Network Systems Science & Advanced Computing

Biocomplexity Institute & Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

October 14th, 2020

(data current to October 13th)

Biocomplexity Institute Technical report: TR 2020-125

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About Us

- Biocomplexity Institute at the University of Virginia
  - Using big data and simulations to understand massively interactive systems and solve societal problems
- Over 20 years of crafting and analyzing infectious disease models
  - Pandemic response for Influenza, Ebola, Zika, and others

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Overview

- **Goal**: Understand impact of COVID-19 mitigations in Virginia
- **Approach:**
  - Calibrate explanatory mechanistic model to observed cases
  - Project infections through December
  - Consider a range of possible mitigation effects in "what-if" scenarios
- **Outcomes:**
  - Ill, Confirmed, Hospitalized, ICU, Ventilated, Death
  - Geographic spread over time, case counts, healthcare burdens

Key Takeaways

Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

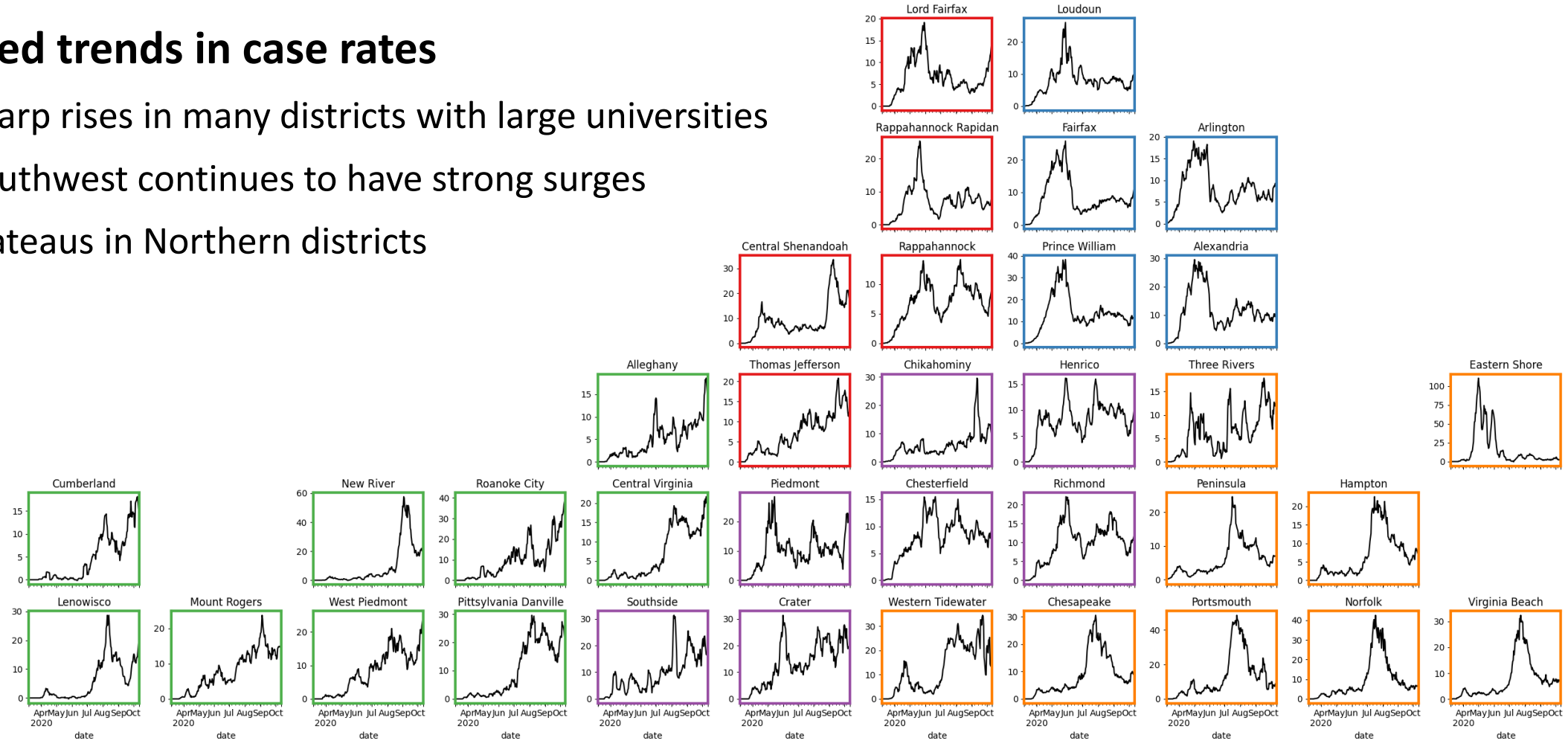
- **Shifting back towards growth, several districts surging with highest yet levels of case rates.**
- VA weekly incidence (12/100K) is up but still below the climbing national average (19.6/100K).
- Projections are mixed, many districts continue to decline, but most are flat or growing.
- Recent updates:
  - Improved smoothing of Adaptive Fitting projections to minimize artifacts.
  - Planning Scenarios moved up to Oct 21st to respond to resurgence in VA and across nation.
- The situation is changing rapidly. Models will be updated regularly.

Situation Assessment

Case Rate (per 100k) by VDH District

Mixed trends in case rates

- Sharp rises in many districts with large universities
- Southwest continues to have strong surges
- Plateaus in Northern districts



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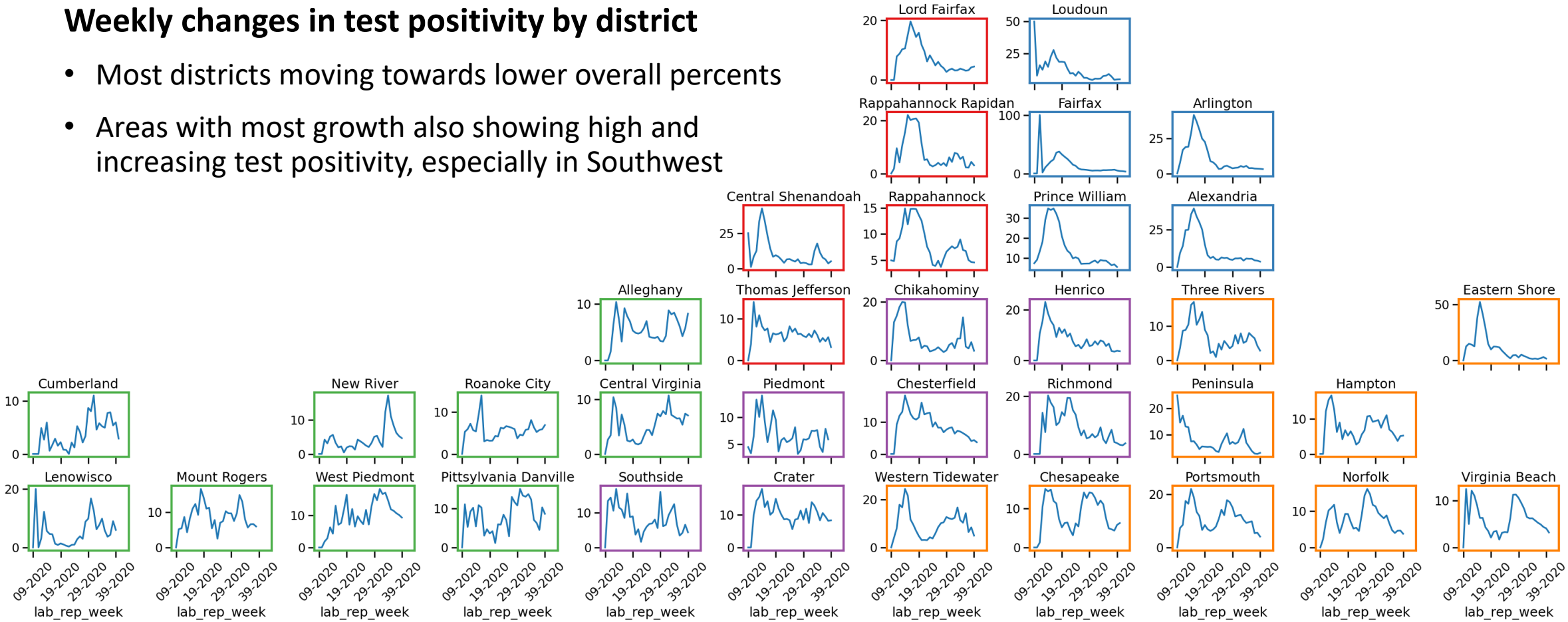
Test Positivity by VDH District

Weekly changes in test positivity by district

- Most districts moving towards lower overall percents
- Areas with most growth also showing high and increasing test positivity, especially in Southwest

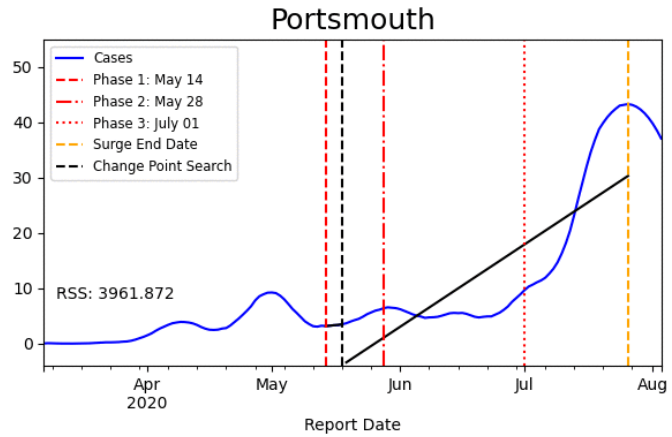


District Trajectories

Goal: Define epochs of a Health District's COVID-19 incidence to characterize the current trajectory

Method: Find recent peak and use hockey stick fit to find inflection point afterwards, then use this period's slope to define the trajectory

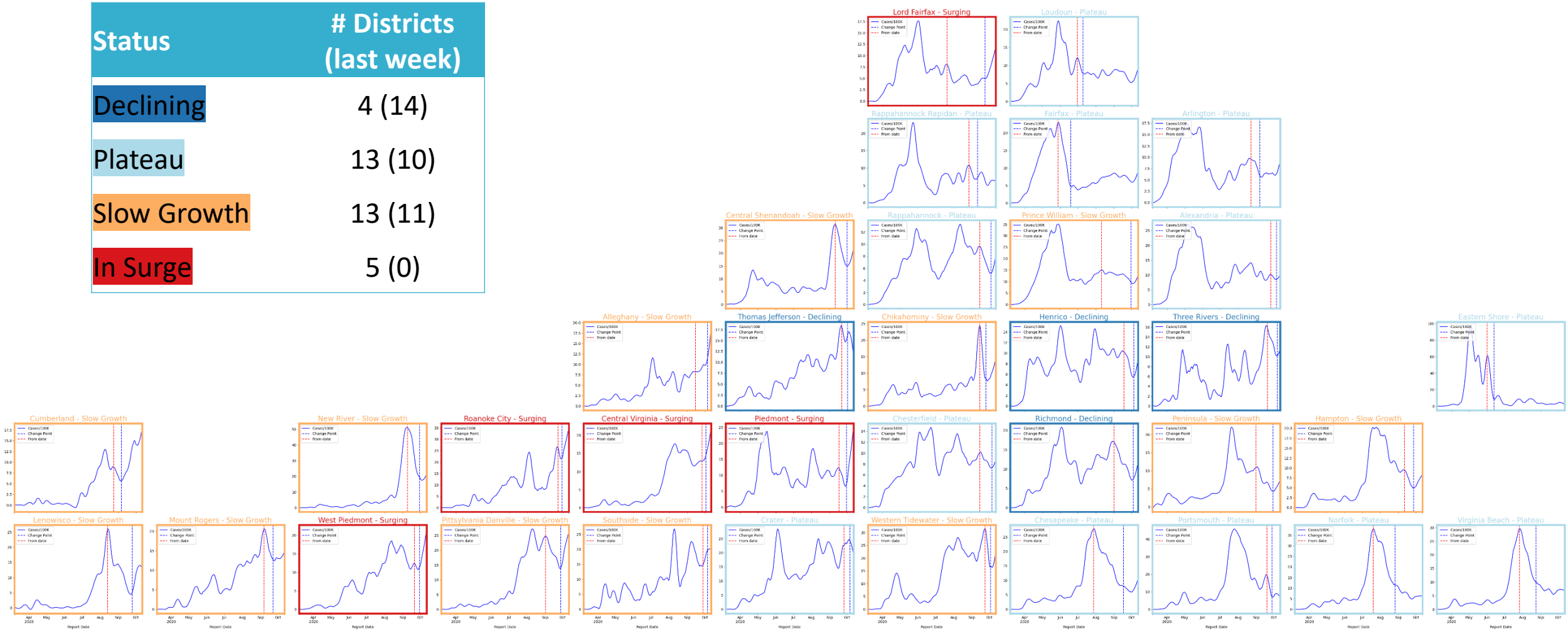
Hockey stick fit



Trajectory	Description	Weekly Case Rate (per 100K) bounds	# Districts (last week)
Declining	Sustained decreases following a recent peak	below -0.9	4 (14)
Plateau	Steady level with minimal trend up or down	above -0.9 and below 0.5	13 (10)
Slow Growth	Sustained growth not rapid enough to be considered a Surge	above 0.5 and below 2.5	13 (11)
In Surge	Currently experiencing sustained rapid and significant growth	2.5 or greater	5 (0)

District Trajectories – Growth predominates

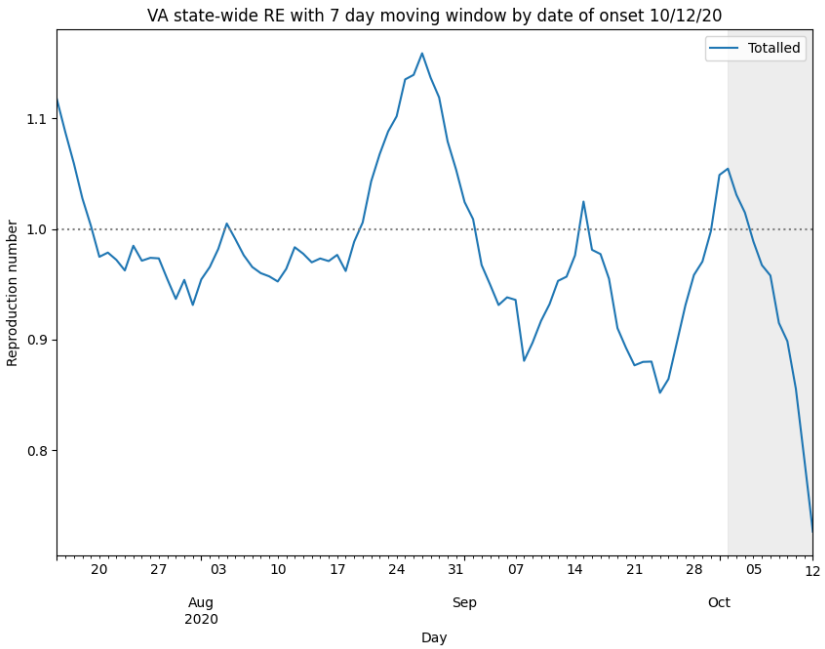
Status	# Districts (last week)
Declining	4 (14)
Plateau	13 (10)
Slow Growth	13 (11)
In Surge	5 (0)

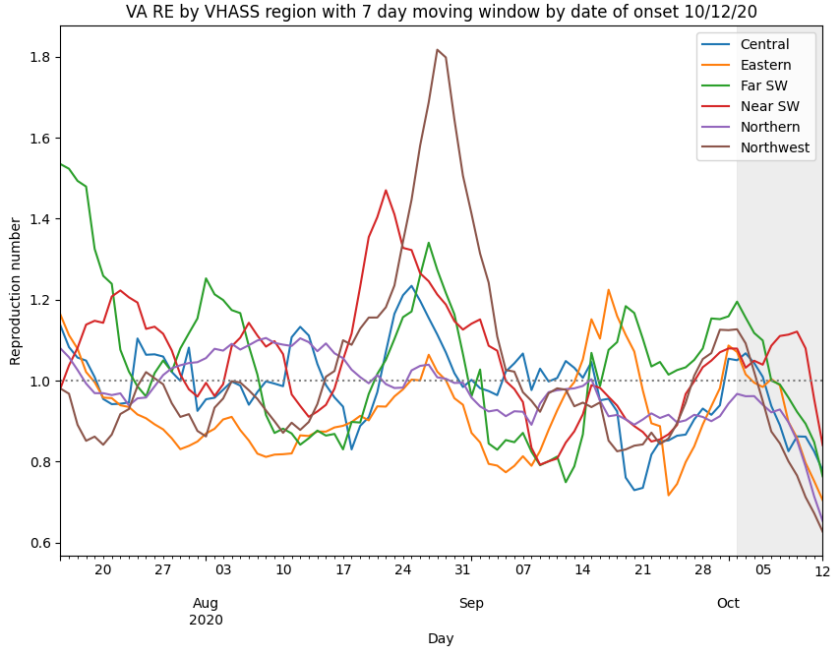


Estimating Daily Reproductive Number

October 3rd Estimates

Region	Current R_e	Diff Last Week
State-wide	1.031	0.178
Central	1.067	0.238
Eastern	1.015	0.226
Far SW	1.155	0.157
Near SW	1.032	0.132
Northern	0.961	0.129
Northwest	1.092	0.183





Methodology

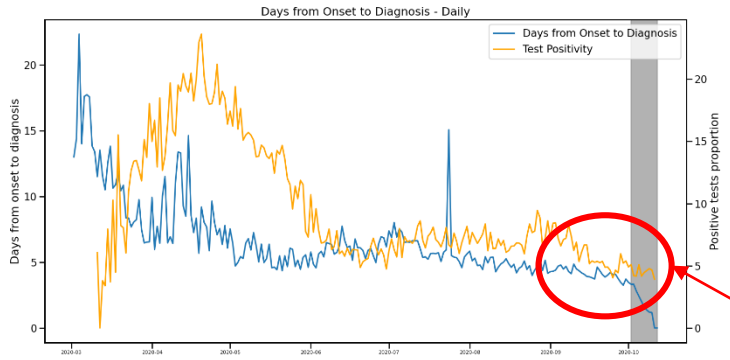
- Wallinga-Teunis method (EpiEstim[1]) for cases by date of onset
- Serial interval: 6 days (2 day std dev)
- Recent estimates may be unstable due to backfill

1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

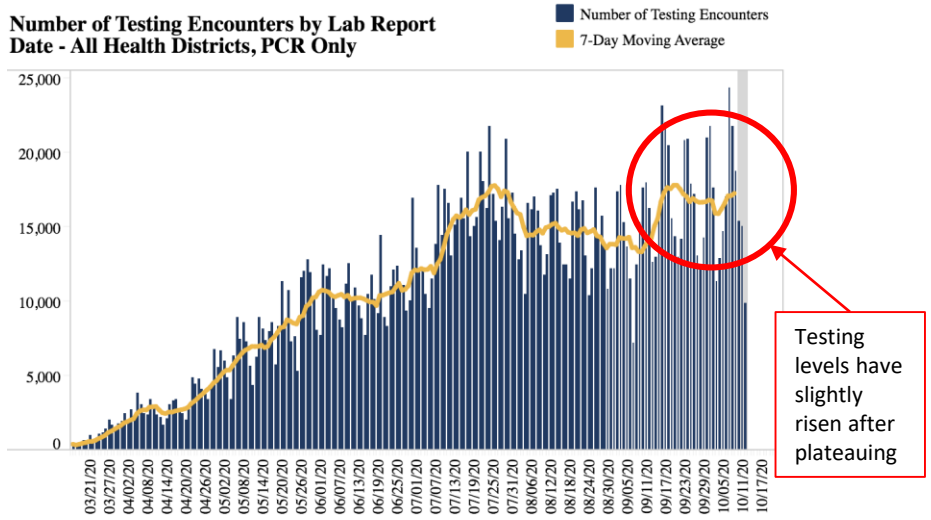
Changes in Case Detection

Timeframe (weeks)	Mean days	% difference from overall mean
April (13-16)	8.54	45%
May (17-21)	5.65	-4%
June (22-25)	5.93	0%
July (26-30)	6.3	7%
Aug (31-34)	4.79	-19%
Sept (35-37)	4.22	-29%
Overall (13-37)	5.91	0%

Test positivity vs. Onset to Diagnosis

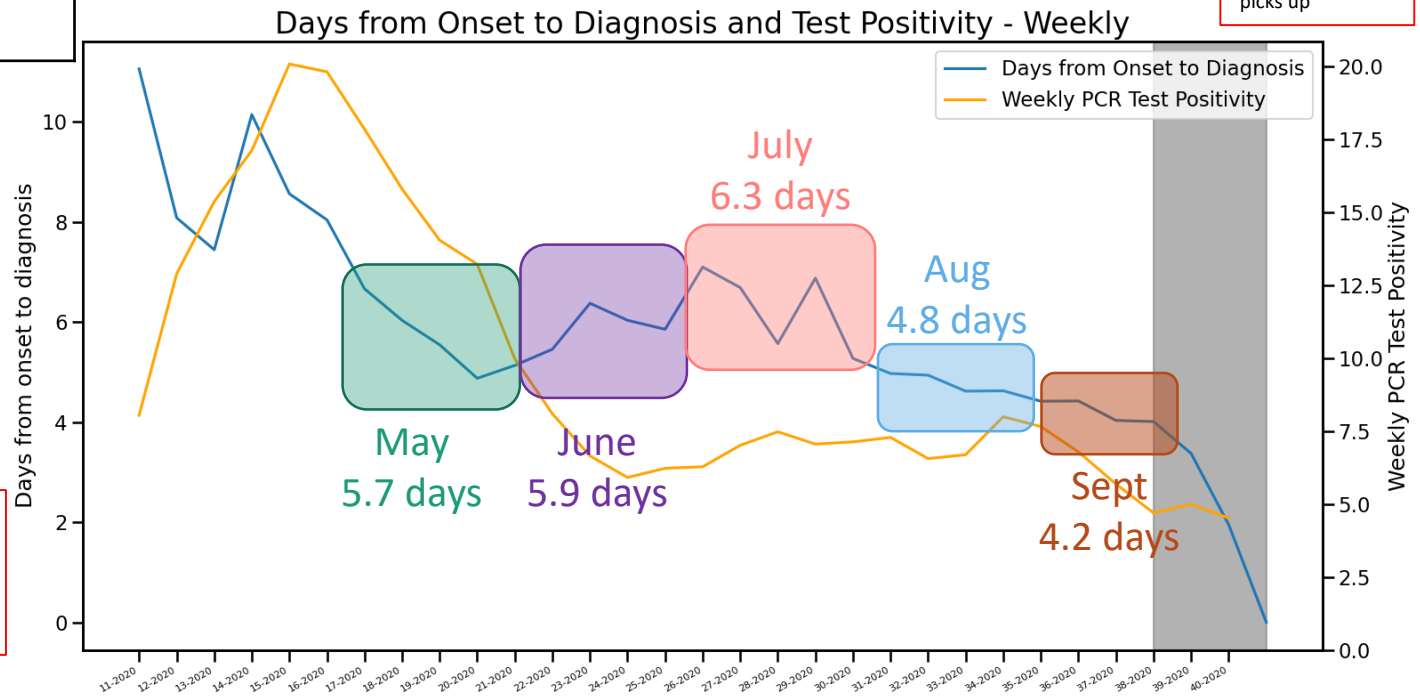


Steady plateau has given way to steady decline in positivity as testing volume picks up

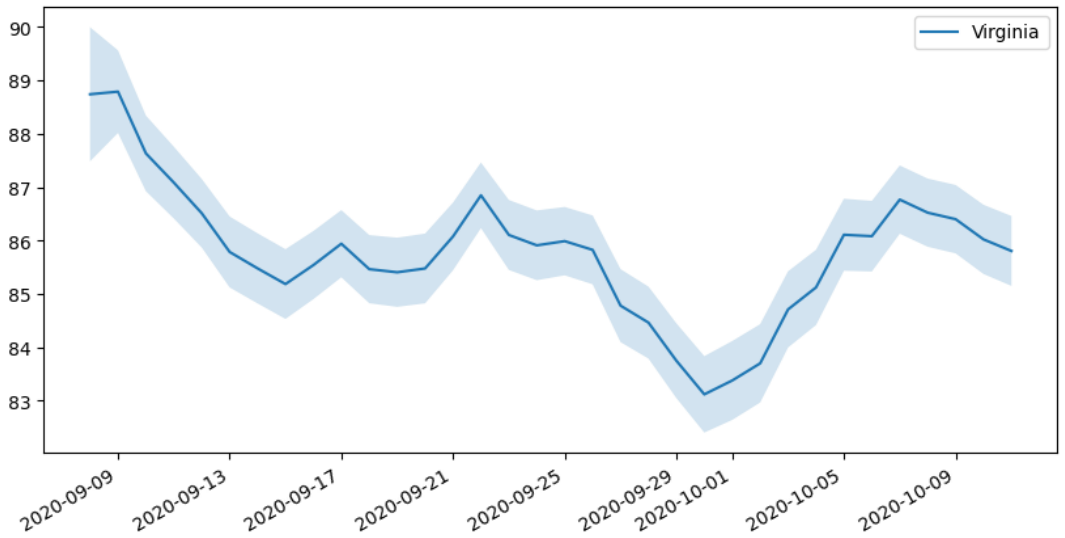


Testing levels have slightly risen after plateauing

Accessed 9:30am October 14, 2020
https://www.vdh.virginia.gov/coronavirus/



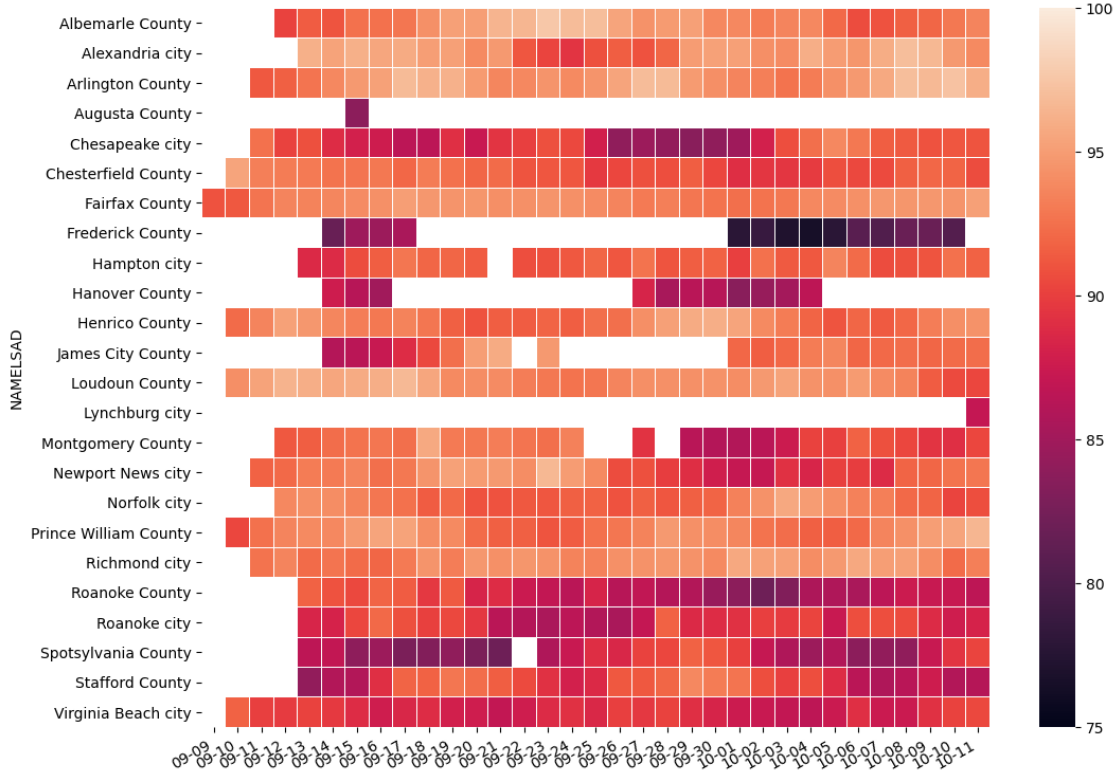
Mask usage in Virginia



State level mask usage as reported via Facebook surveys over the past month shows ranges from 83% to 89%

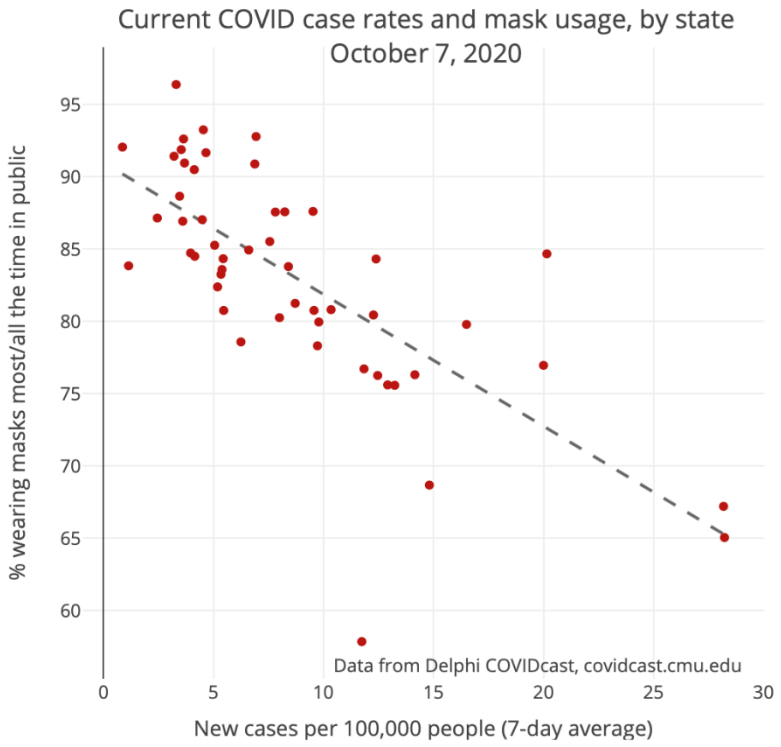
- Relatively stable over time
- Limited variance across the commonwealth
- ~3000 daily responses from VA.

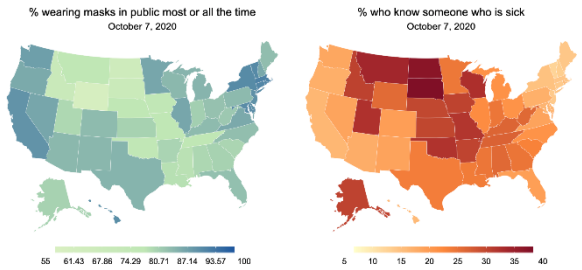
Data Source: https://covidcast.cmu.edu



Some fluctuations over the last month in specific counties. Data quality may be affected by sample sizes.

Mask usage and Case Rates



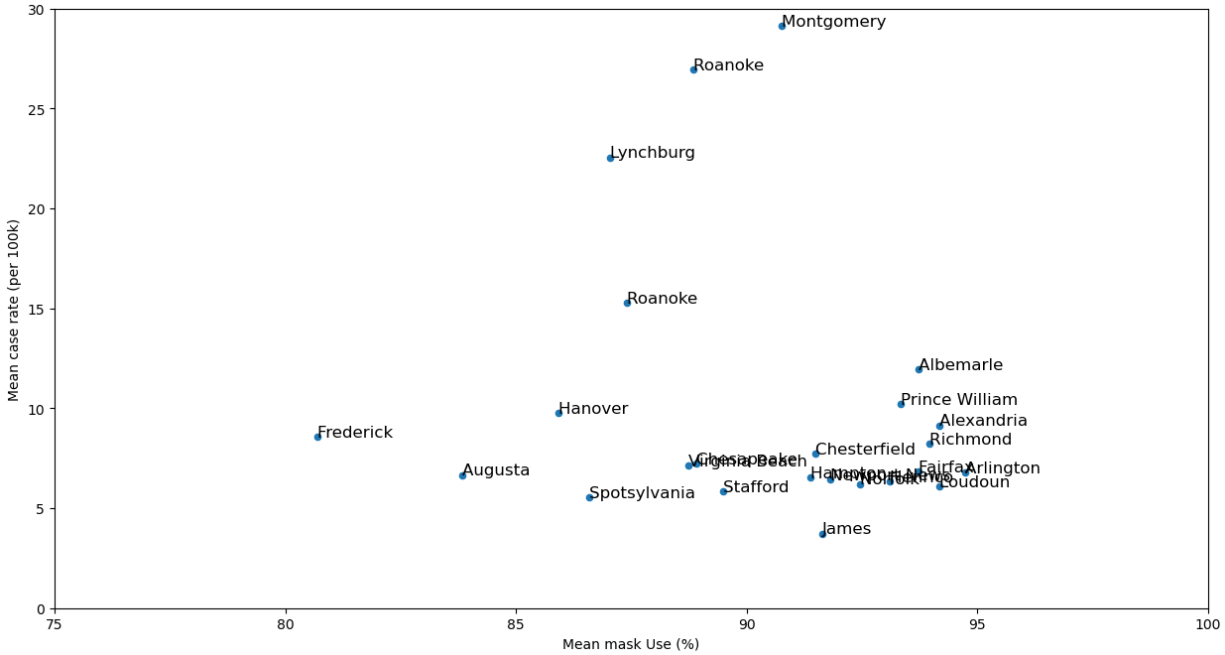


https://delphi.cmu.edu/blog/2020/10/12/new-and-improved-covid-symptom-survey-tracks-testing-and-mask-wearing/

Nationally strong correlation seen with mask wearing in a state and its recent case rates

Same correlation not found across VA counties

- University counties disrupt correlation
- VA counties vary less than the states in mask usage



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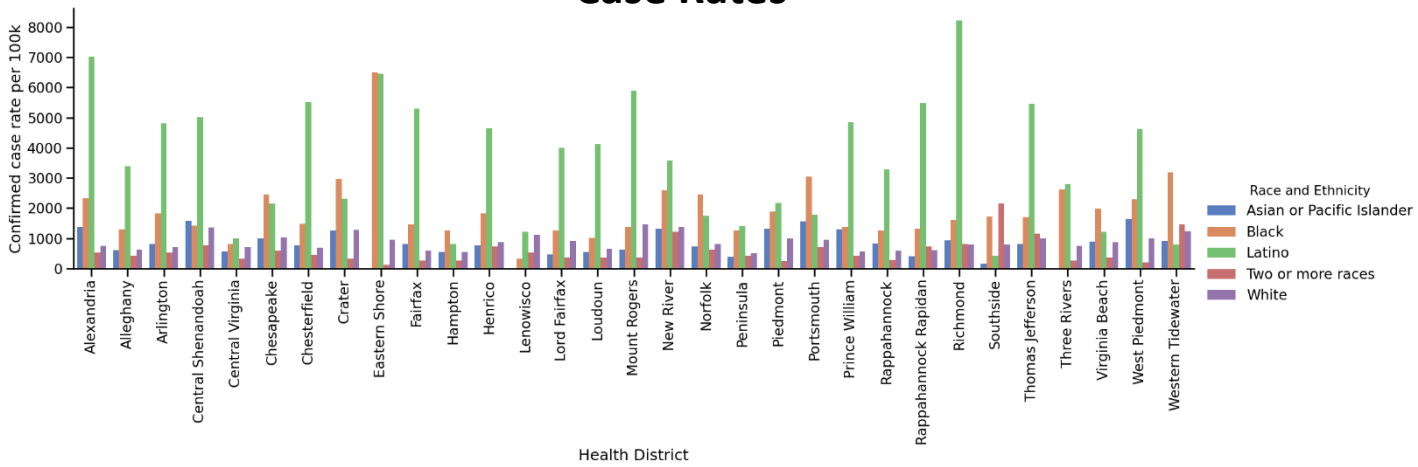
Race and Ethnicity cases per 100K

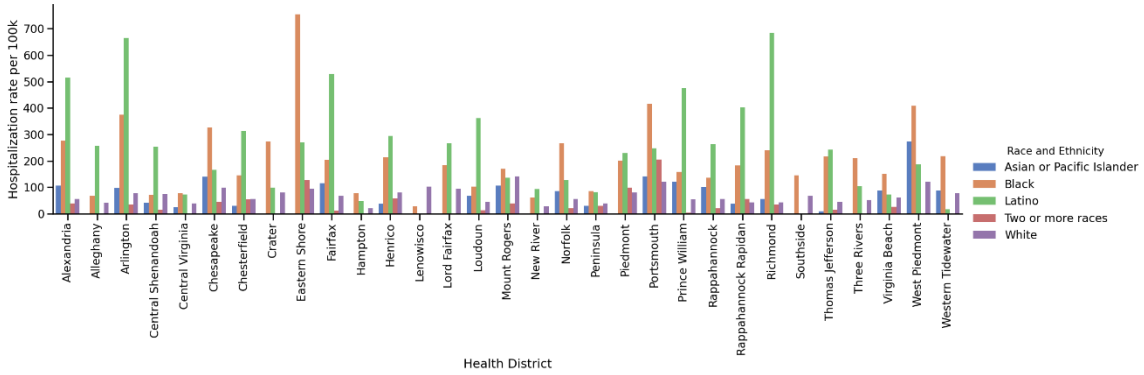
Rates per 100K of each Racial-Ethnic population by Health District

- Black and Latino populations have much higher, case, hospitalization, and death rates
- More pronounced in some districts
- Based on 2019 census race-ethnicity data by county

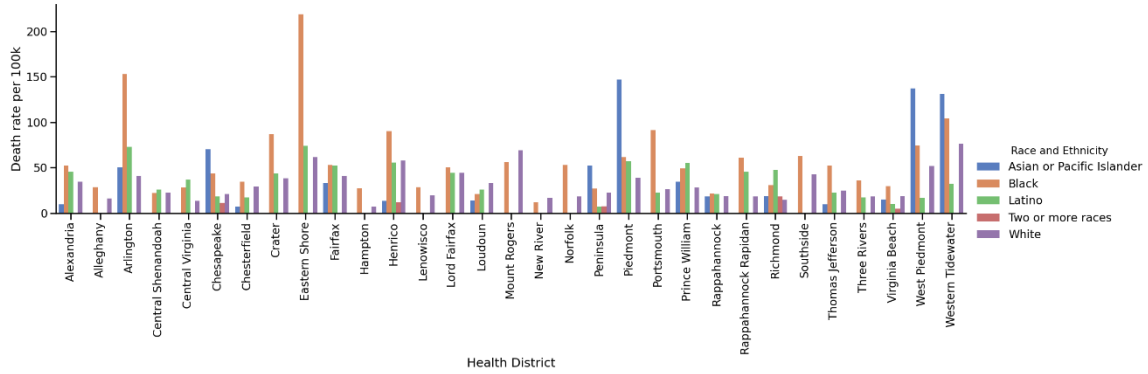
Case Rates



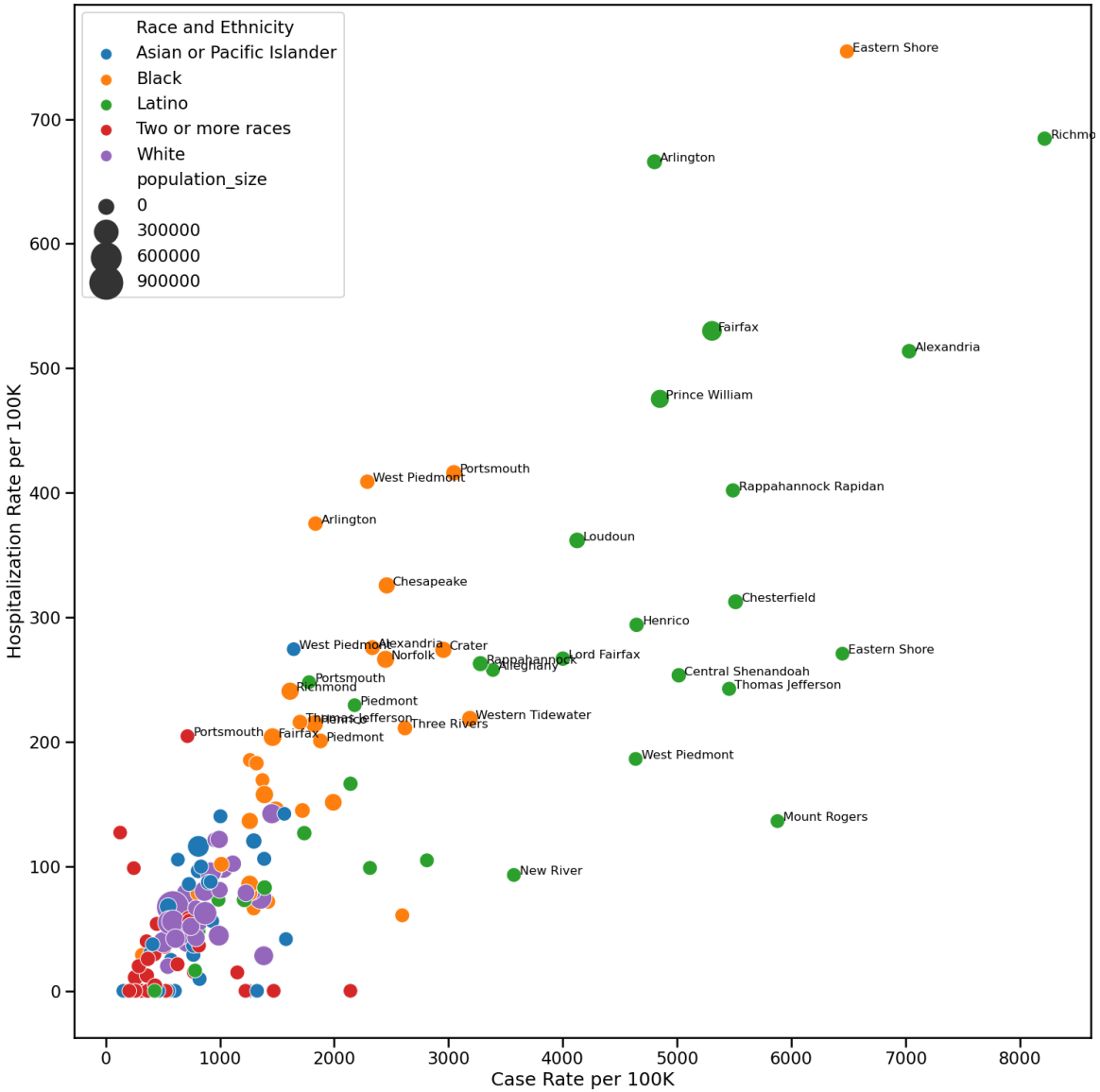
Hospitalization Rates



Death Rates



Race and Ethnicity cases per 100K



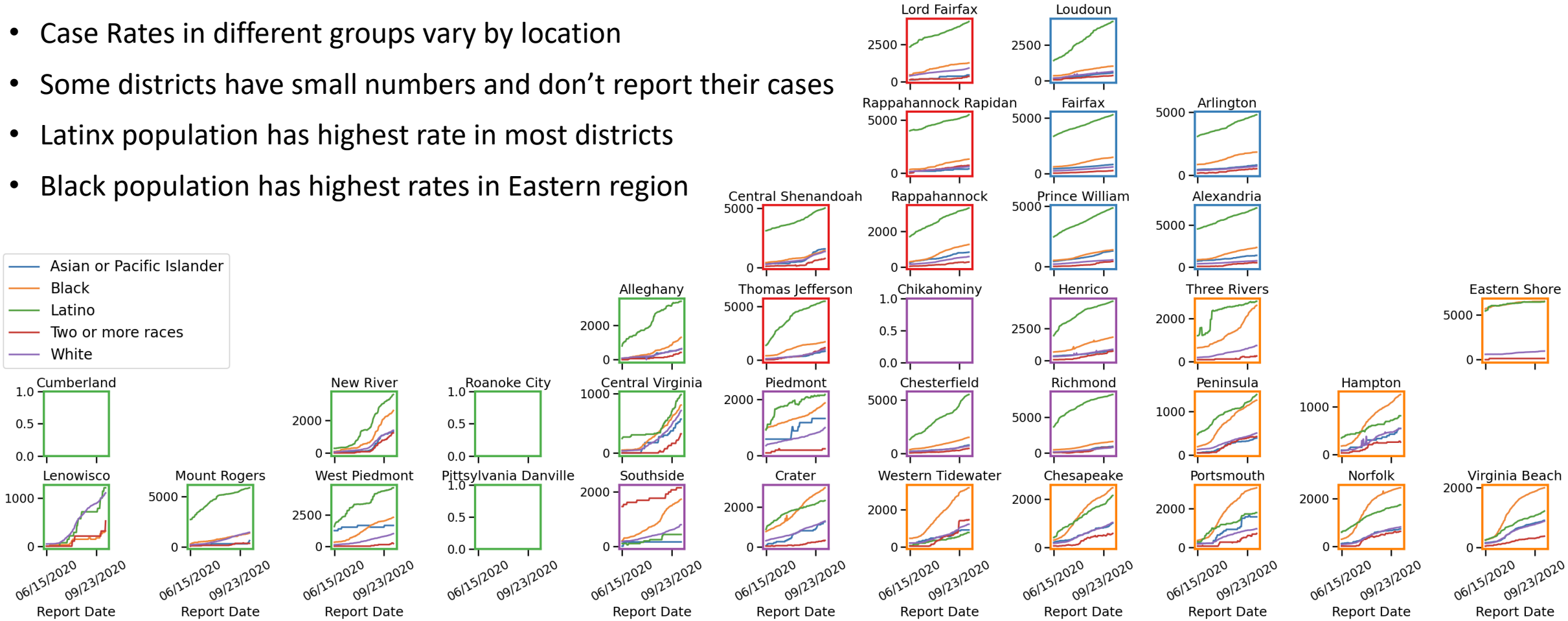
Rates per 100K of each Racial-Ethnic population by Health District

- Each Health District's Racial-Ethnic population is plotted by their Hospitalization and Case Rate
- Points are sized based on their overall population size
- Overlapping labels removed for clarity

Race and Ethnicity Attack Rates (per 100K)

Cumulative Race and Ethnicity Attack Rates (per 100k)

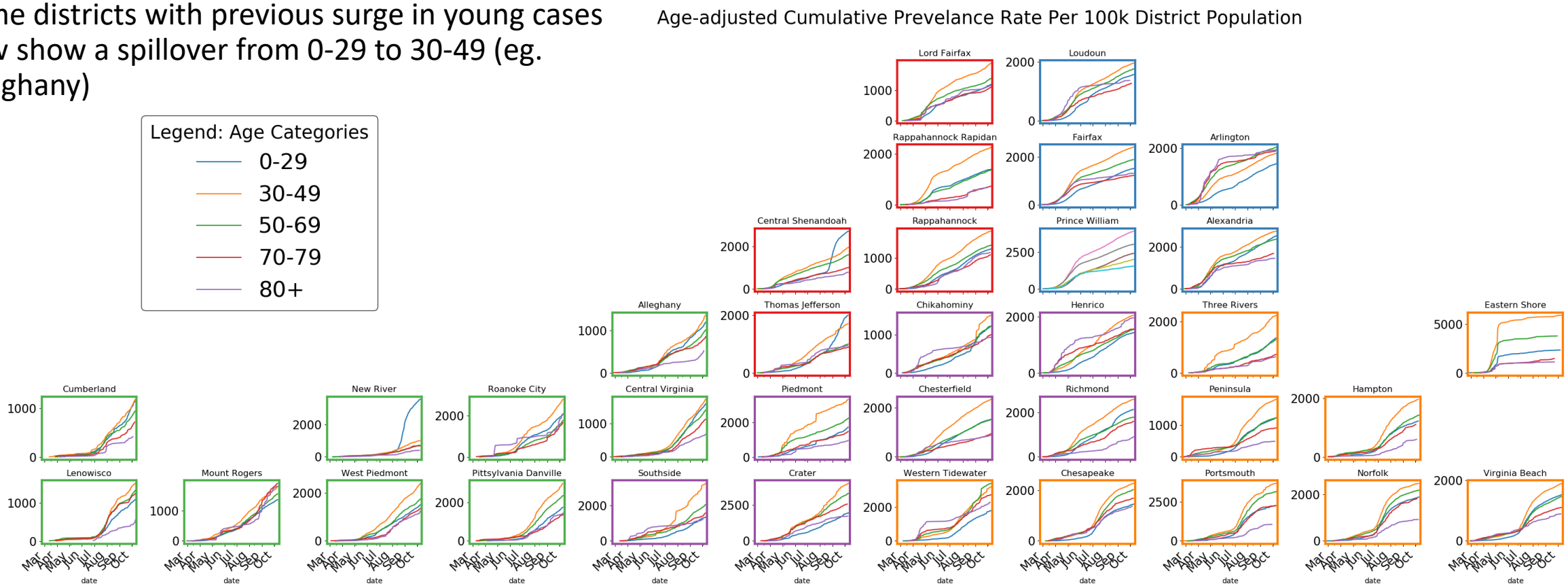
- Case Rates in different groups vary by location
- Some districts have small numbers and don't report their cases
- Latinx population has highest rate in most districts
- Black population has highest rates in Eastern region



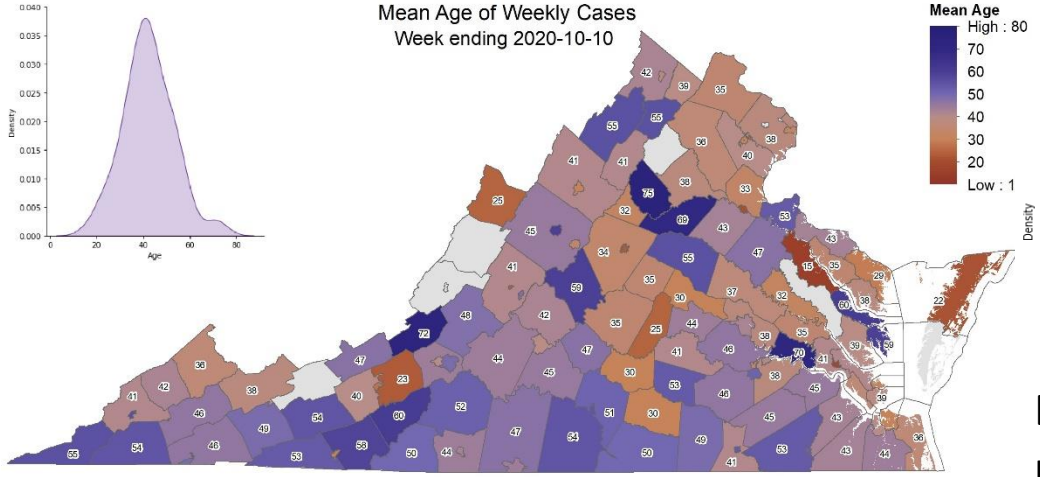
Age-Specific Attack Rates (per 100K)

Cumulative Age-specific Attack Rates (per 100k)

- Younger age groups outpace older in many districts
- Some districts with previous surge in young cases now show a spillover from 0-29 to 30-49 (eg. Alleghany)



Age-Specific Case Prevalence



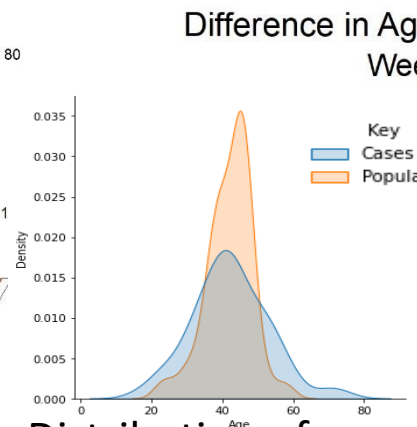
What is the average age of the cases by county?

Younger cases in Northern VA, Far SW, Tidewater, and around universities

How different is this from the Population?

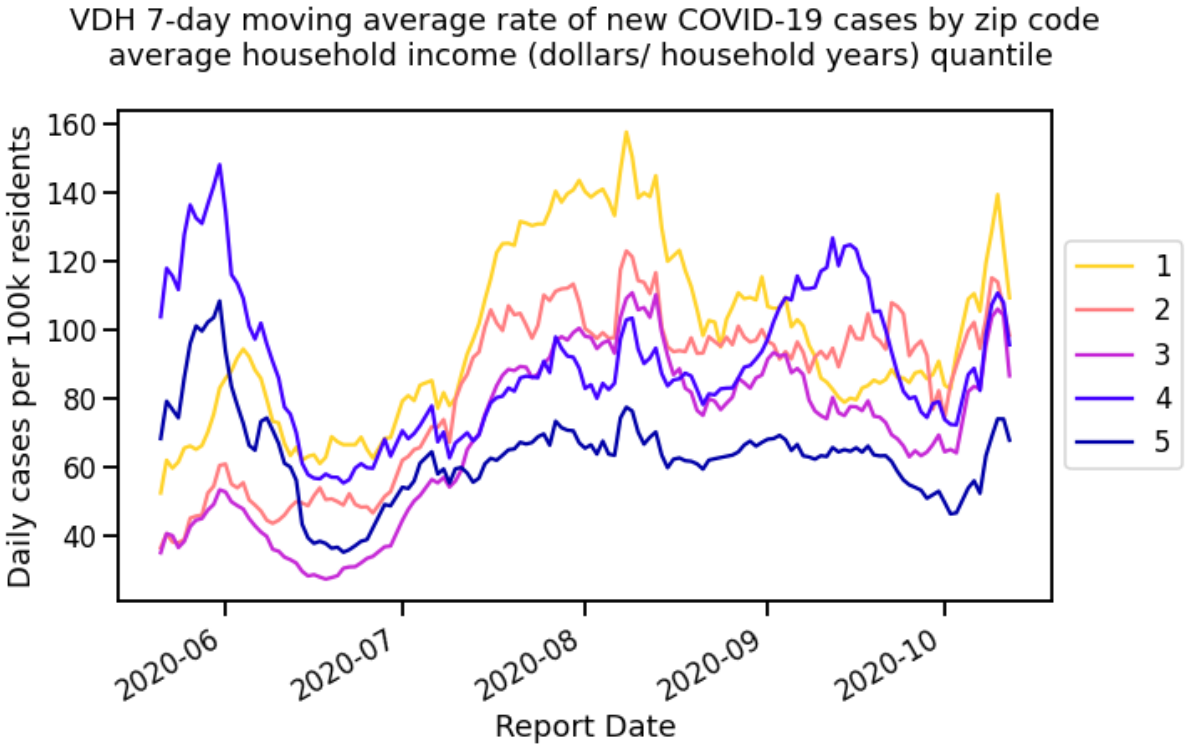
Difference in mean age of cases vs. population as a whole

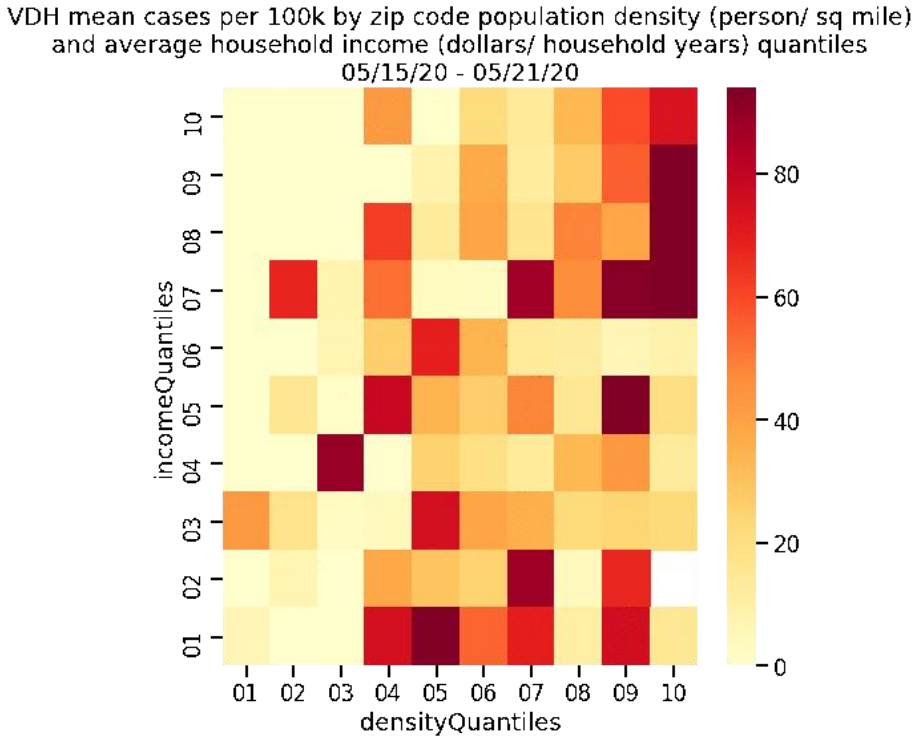
Purple = Cases are older than pop; Green = Cases are younger than pop



Distribution of means of counties

Impact across Density and Income



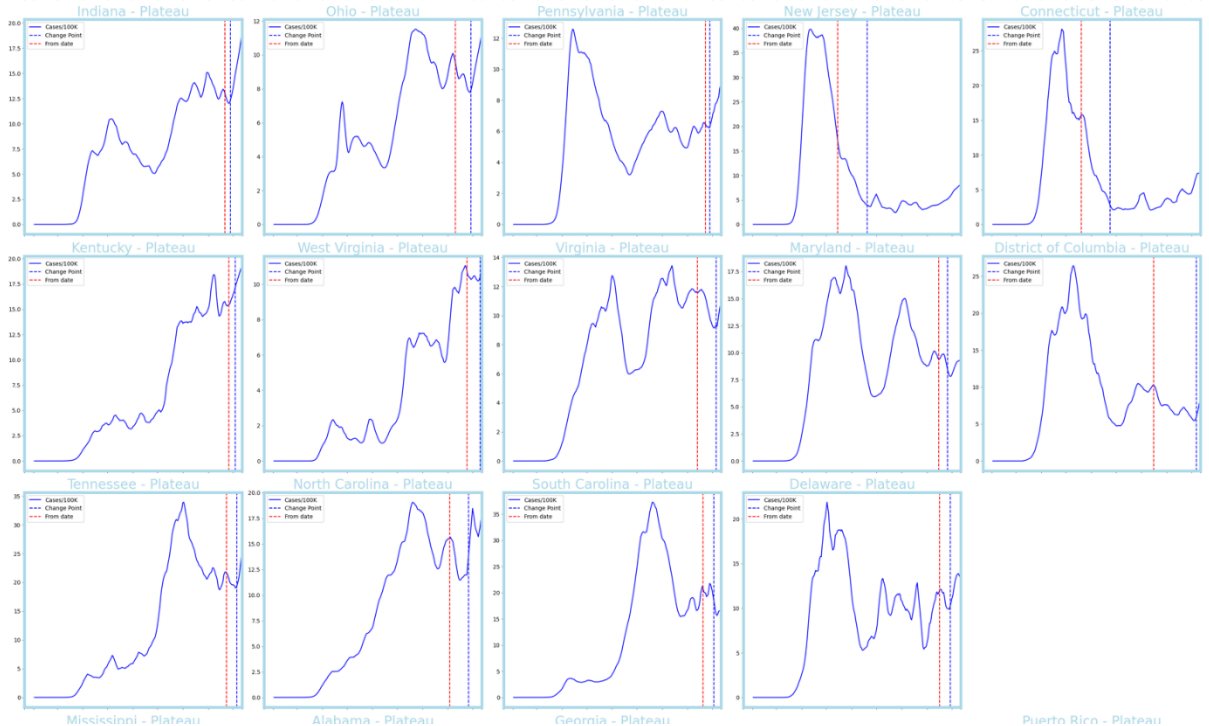


Shift back to higher income zip codes partially driven by surges in areas surrounding universities

Can see the evolution from denser and wealthier zip codes to poorer and less dense zip codes, then recently back to denser wealthier zip codes

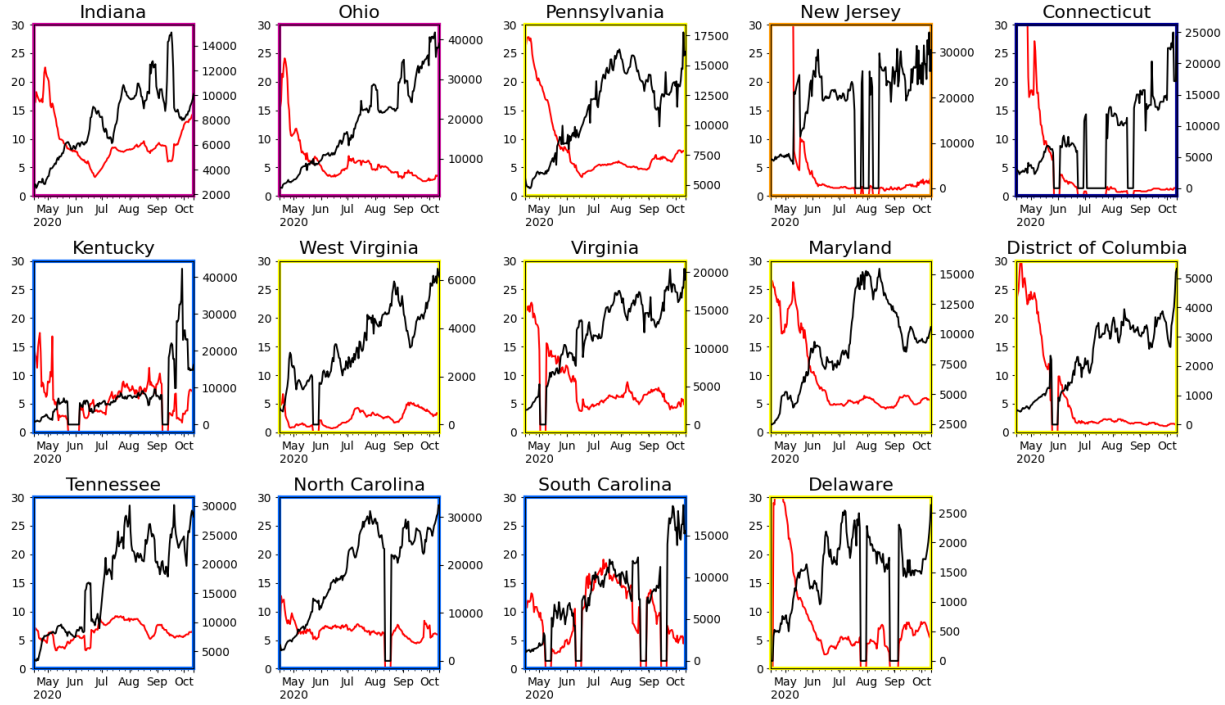
Other State Comparisons

Trajectories of States



- VA and all neighbors plateauing
- Slight mixed trends but within the bounds of steady
- Case rates over 10/100K in VA, KY, TN, NC, SC, DE, and WV

Tests per Day and Test Positivity



- Test positivity mixed, VA's declining rate has slowed.
- Testing volumes steady in most states

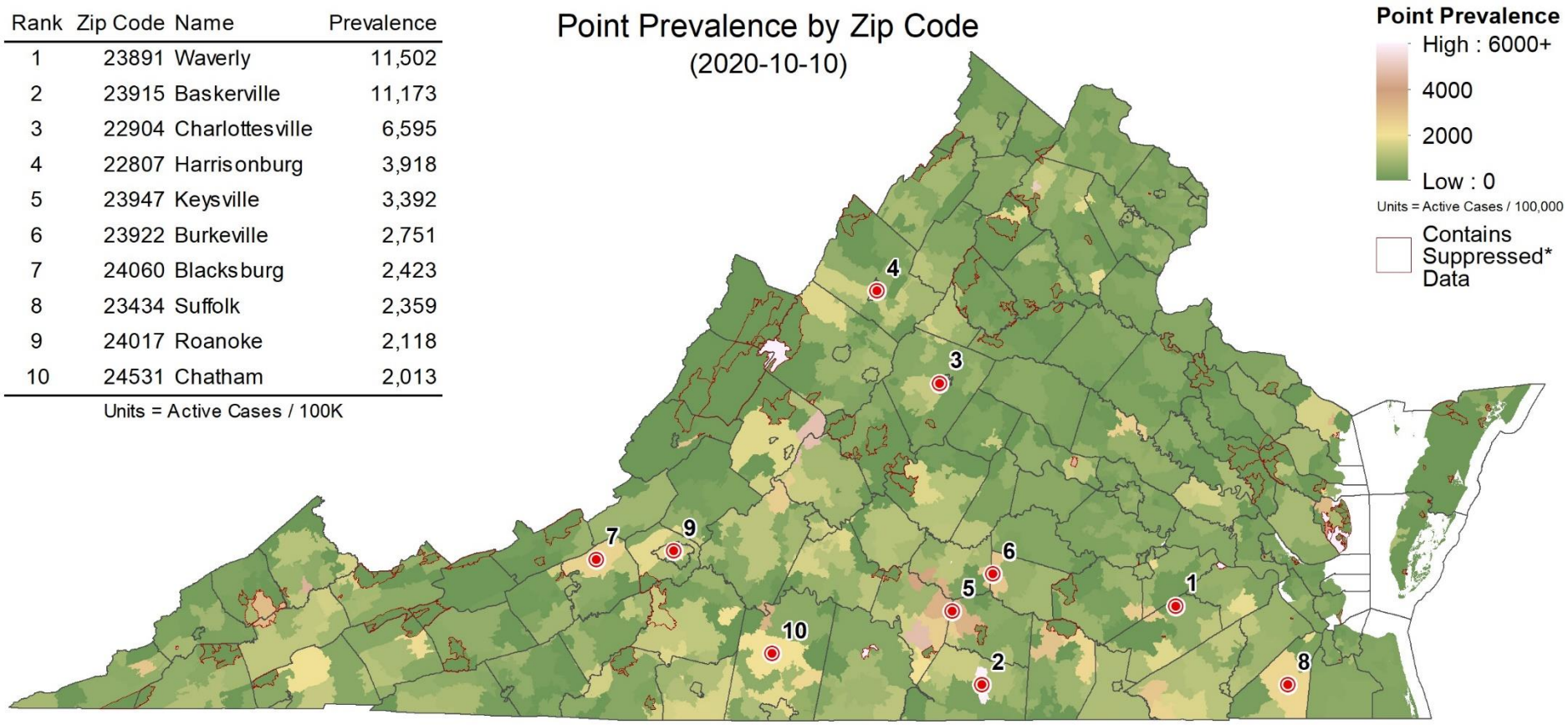
Zip code level weekly Case Rate (per 100K)

Case Rates in the last week by zip code

- Concentrations of very high prevalence in some zip codes
- Overall higher prevalence
- High prevalence zips scattered across the commonwealth
- Some counts are low and suppressed to protect anonymity, those are shown in white

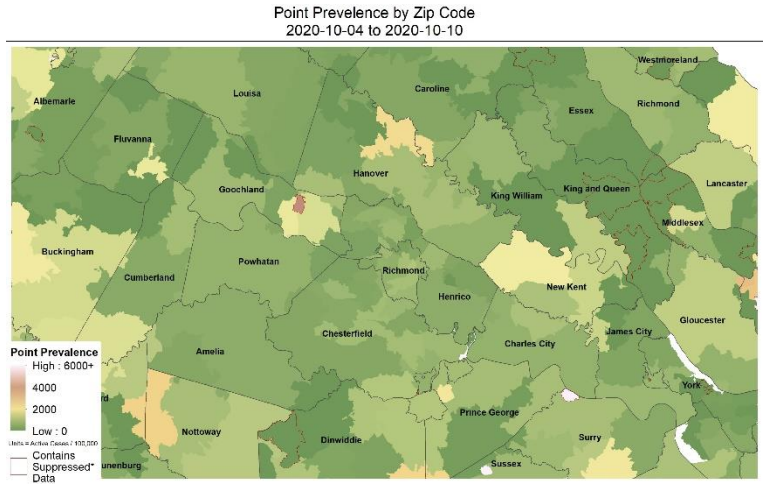
Rank	Zip Code	Name	Prevalence
1	23891	Waverly	11,502
2	23915	Baskerville	11,173
3	22904	Charlottesville	6,595
4	22807	Harrisonburg	3,918
5	23947	Keysville	3,392
6	23922	Burkeville	2,751
7	24060	Blacksburg	2,423
8	23434	Suffolk	2,359
9	24017	Roanoke	2,118
10	24531	Chatham	2,013

Units = Active Cases / 100K

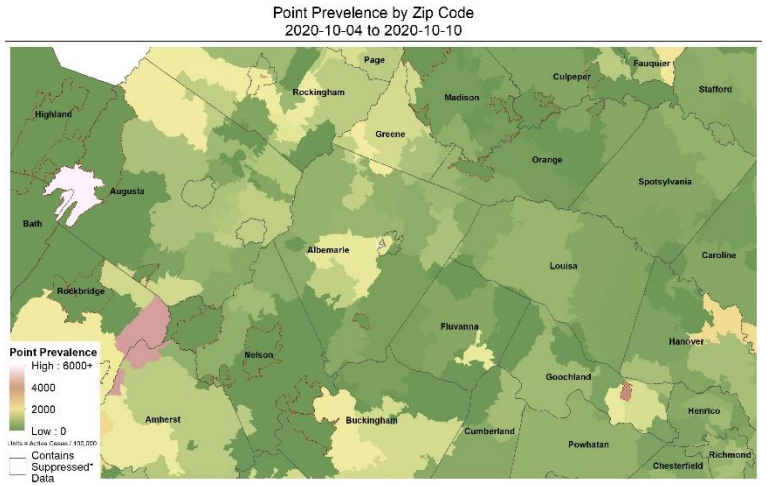


Zip code level weekly Case Rate (per 100K)

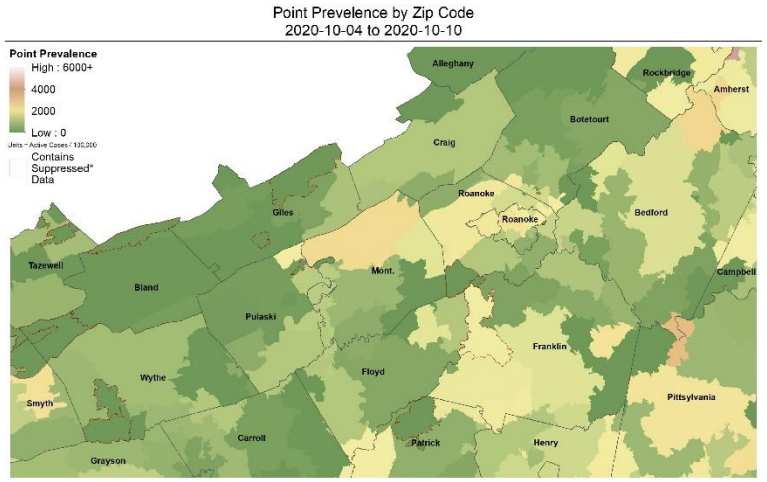
Richmond



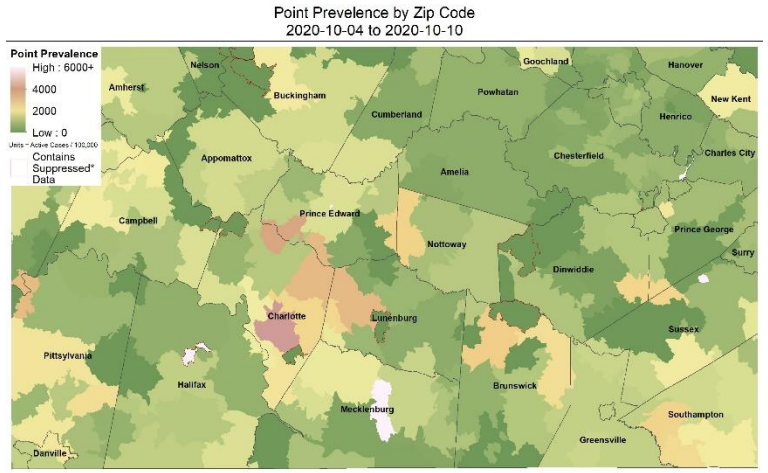
Albemarle



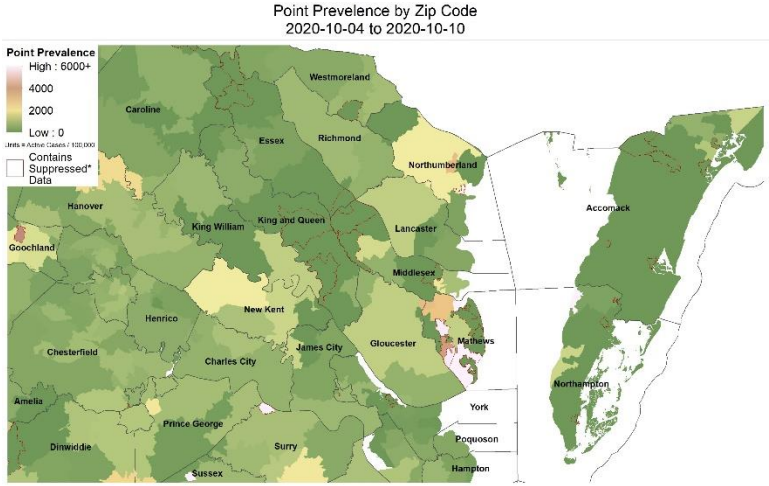
New River Valley



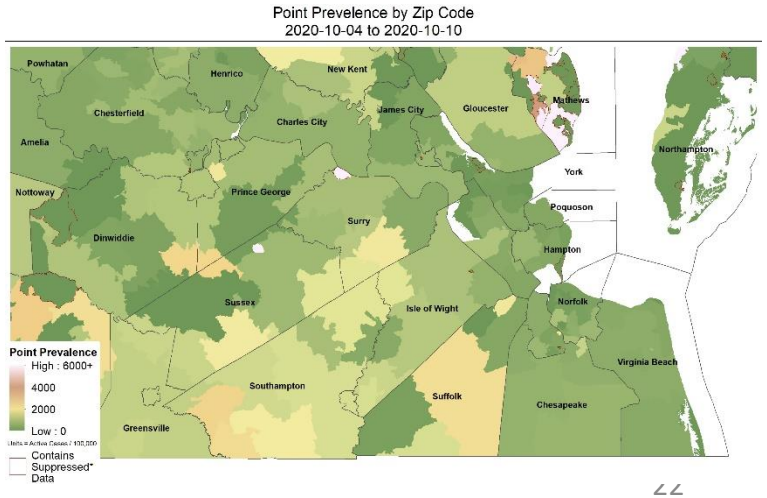
Southside



Three Rivers

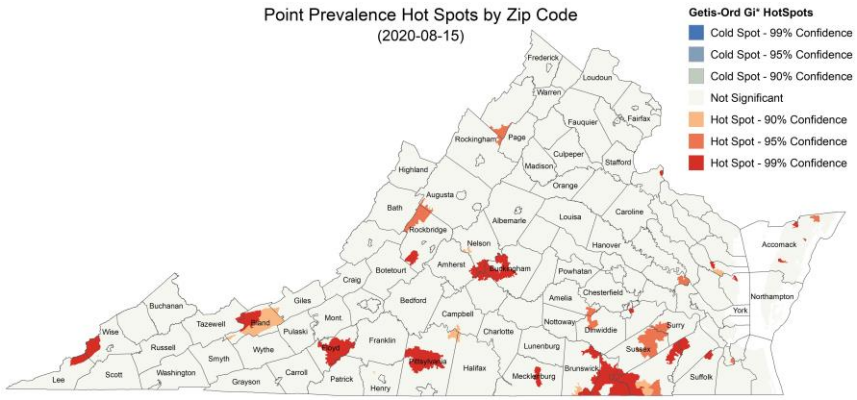


Tidewater



Zip Code Hot Spots

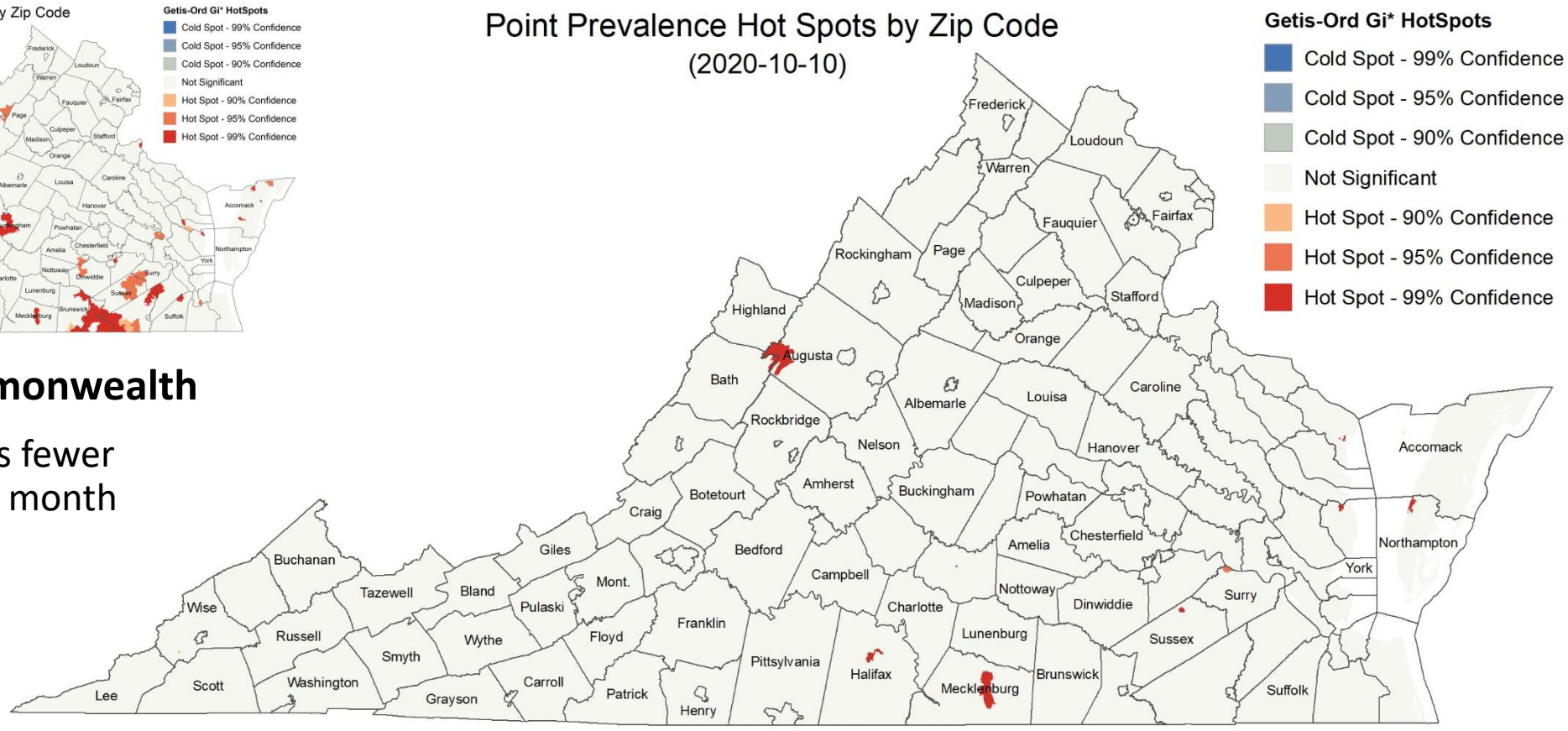
Previous weeks



Hotspots across commonwealth

- General trend towards fewer hotspots over the last month

Hot Spot Significance	# of Zips (last week)
99%	8 (12)
95%	1 (7)
90%	1 (3)



Model Update – Adaptive Fitting

Adaptive Fitting Approach

Each county fit precisely, with recent trends used for future projection

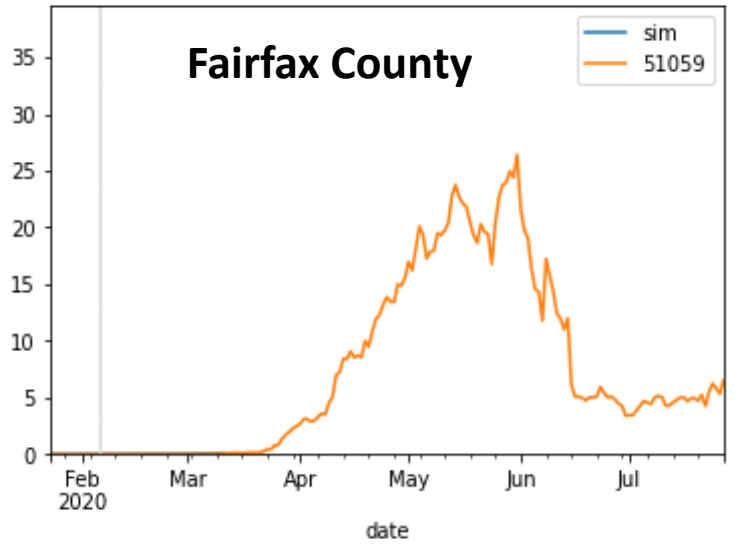
- Allows history to be precisely captured, and used to guide bounds on projections

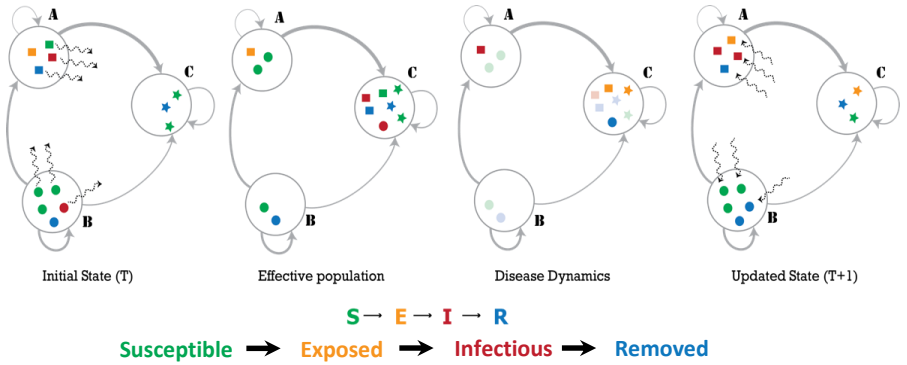
Model: An alternative use of the same meta-population model, PatchSim

- Allows for future "what-if" Scenarios to be layered on top of calibrated model
- Eliminates connectivity between patches, to allow calibration to capture the increasingly unsynchronized epidemic

External Seeding: Steady low-level importation

- Widespread pandemic eliminates sensitivity to initial conditions
- Uses steady 1 case per 10M population per day external seeding





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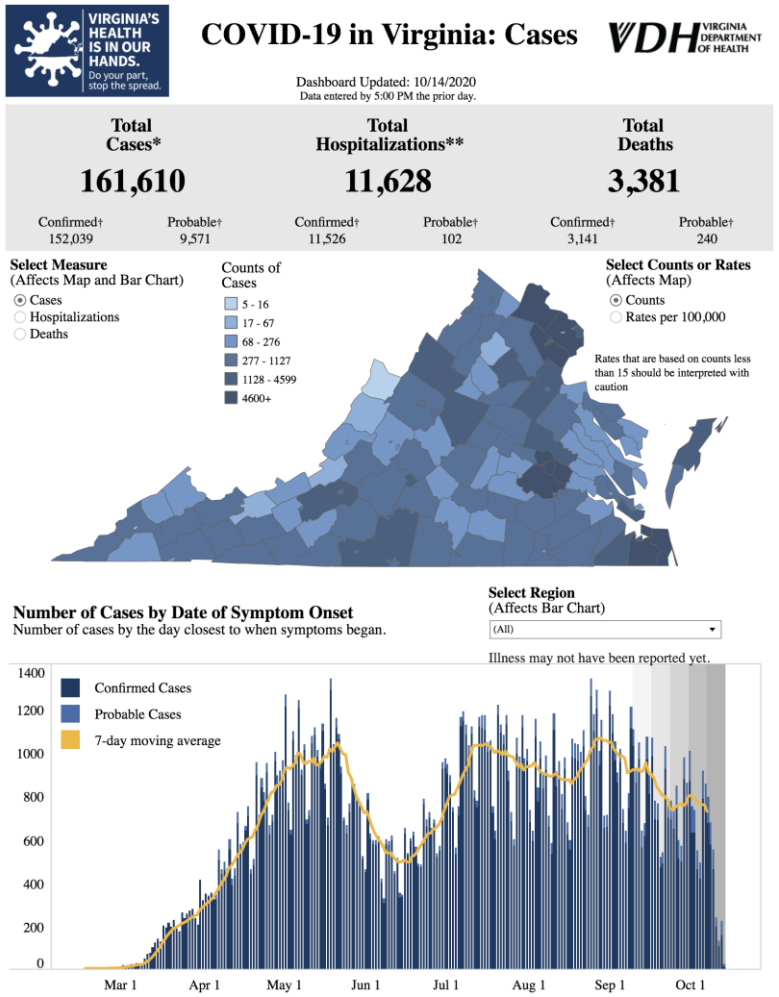
Calibration Approach

- **Data:**
  - County level case counts by date of onset (from VDH)
  - Confirmed cases for model fitting
- **Calibration:** fit model to observed data
  - Tune transmissibility across ranges of:
    - Duration of incubation (5-9 days), infectiousness (3-7 days)
    - Undocumented case rate (2x to 15x)
    - Detection delay: exposure to confirmation (4-12 days)
  - Approach captures uncertainty, but allows model to precisely track the full trajectory of the outbreak
- **Project:** future cases and outcomes using the most recent parameters with constraints learned from the history of the fit parameters
  - Mean trend from last 7 days used, adjusted by variances in the previous 3 weeks
  - 1 week interpolation to smooth transitions in rapidly changing trajectories
  - Particles with high error or variance filtered out



Accessed 9:30am October 14, 2020
https://www.vdh.virginia.gov/coronavirus/

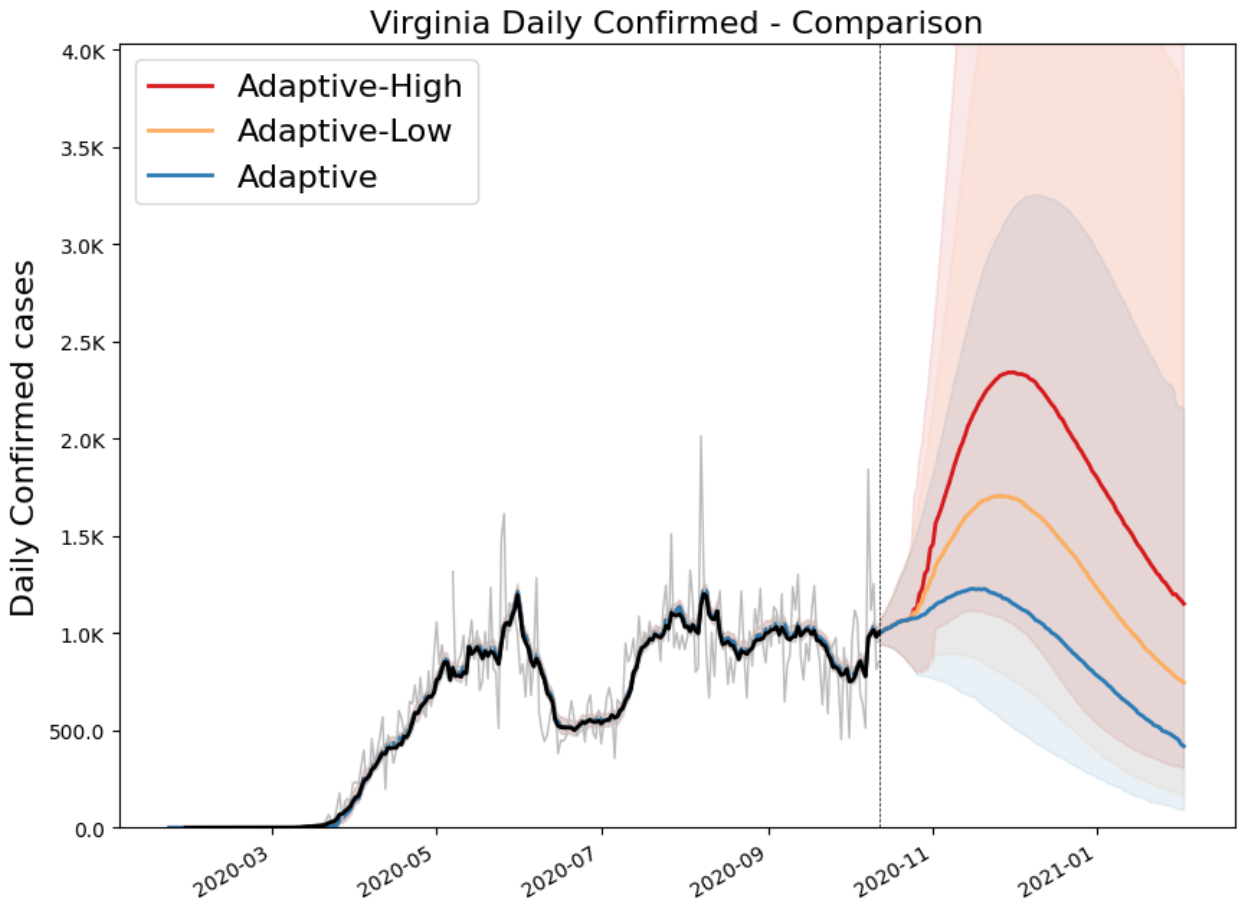
Scenarios – Seasonal Effects

- Societal changes in the coming weeks have lead to an increase in transmission rates
  - Start of in-person school
  - Changes to workplace attendance
  - Seasonal impact of weather patterns
- Three scenarios provided to capture possible trajectories related to these changes starting Oct 21st, 2020
  - Adaptive: No change from base projection
  - Adaptive-Low: 15% increase in transmission starting Oct 21st, 2020
  - Adaptive-High: 30% increase in transmission starting Oct 21st, 2020

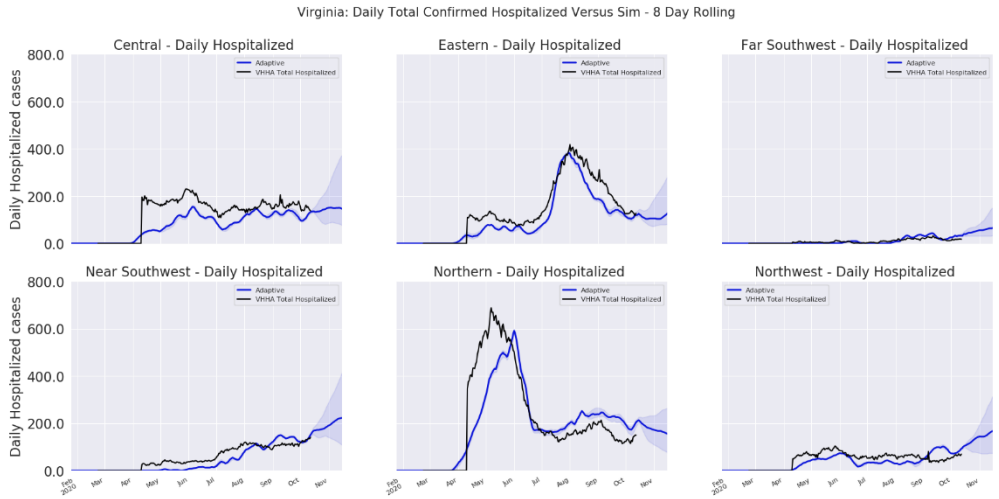
Model Results

Outcome Projections

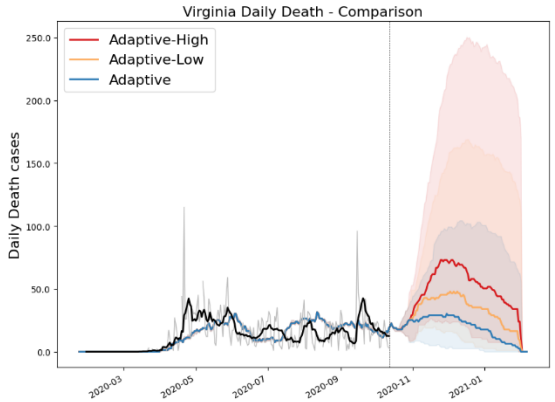
Confirmed cases



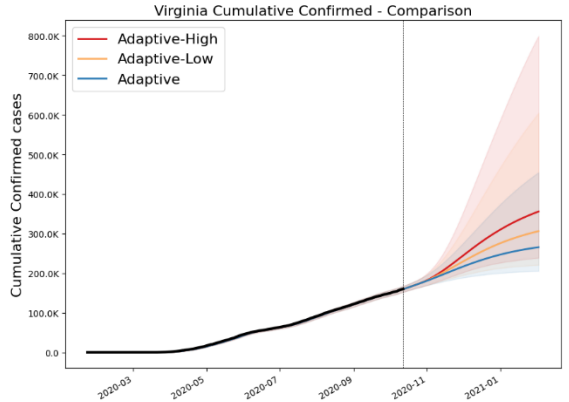
Estimated Hospital Occupancy



Daily Deaths



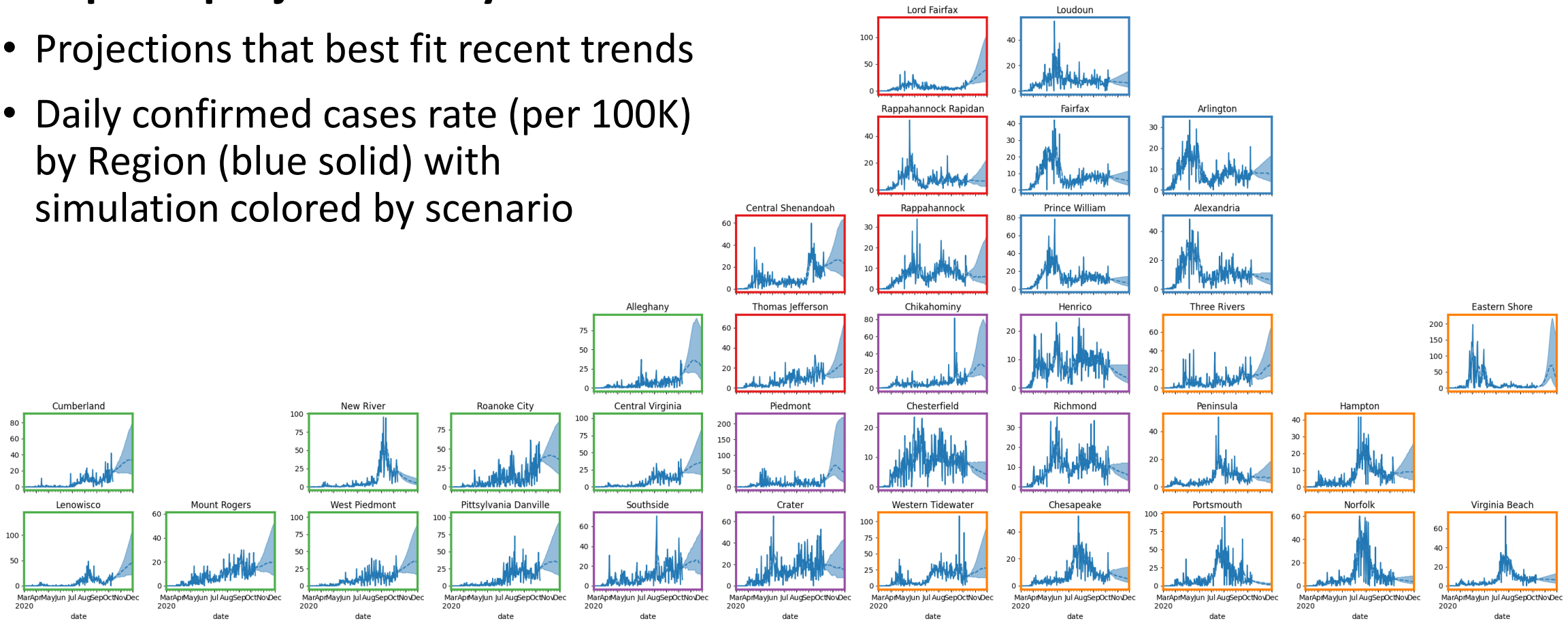
Cumulative Confirmed cases



District Level Projections: Adaptive

Adaptive projections by District

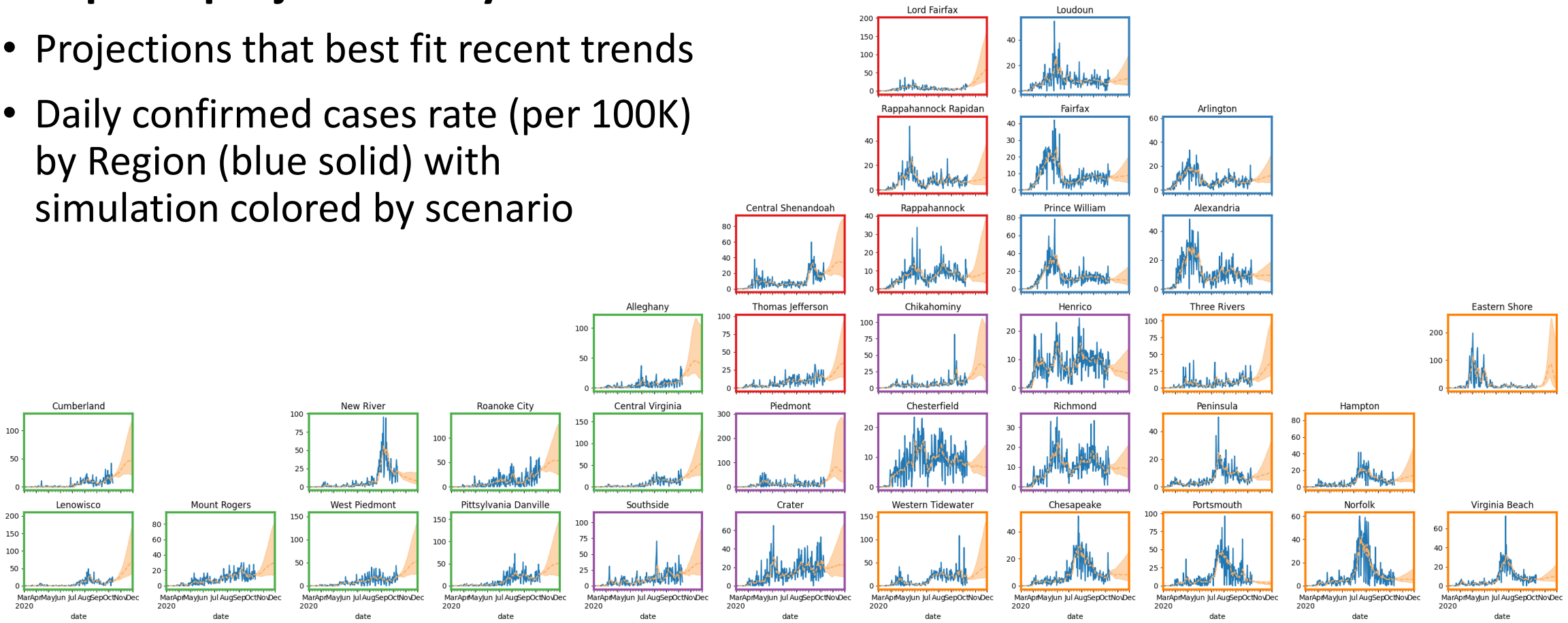
- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario



District Level Projections: Adaptive-Low

Adaptive projections by District

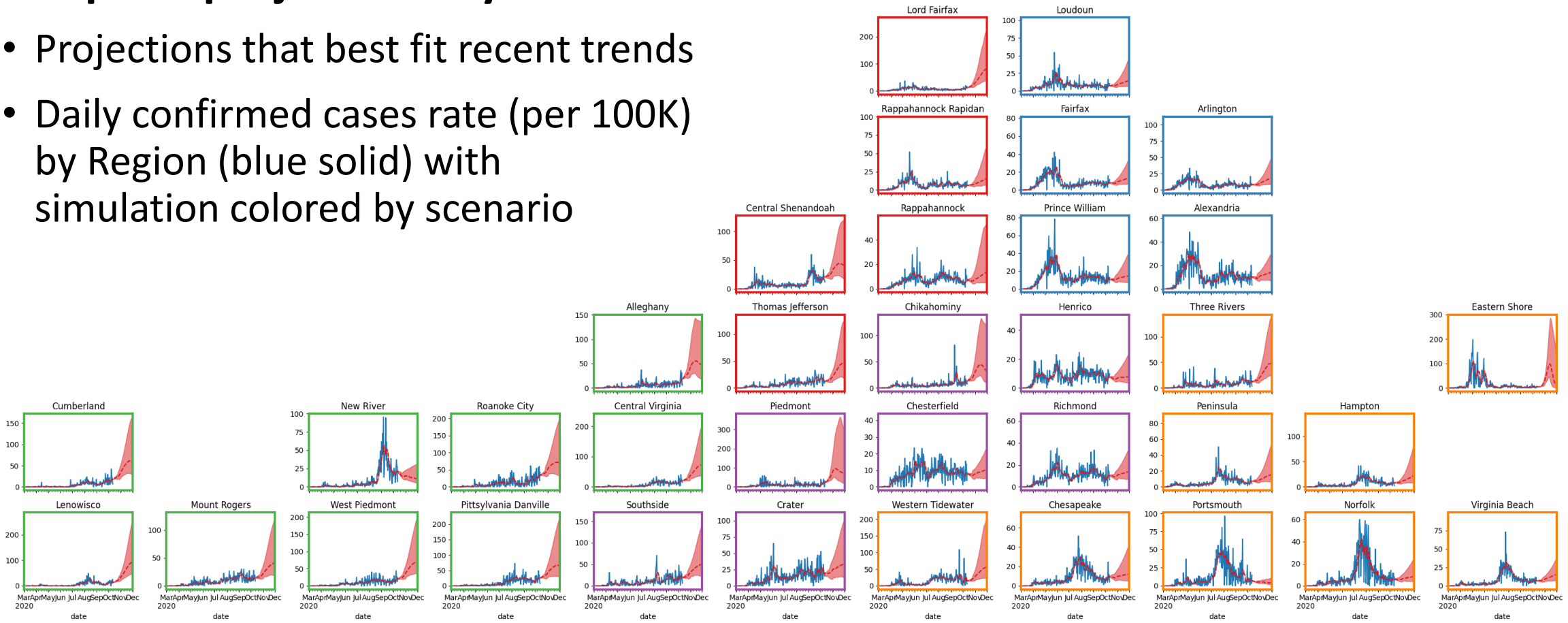
- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario



District Level Projections: Adaptive-High

Adaptive projections by District

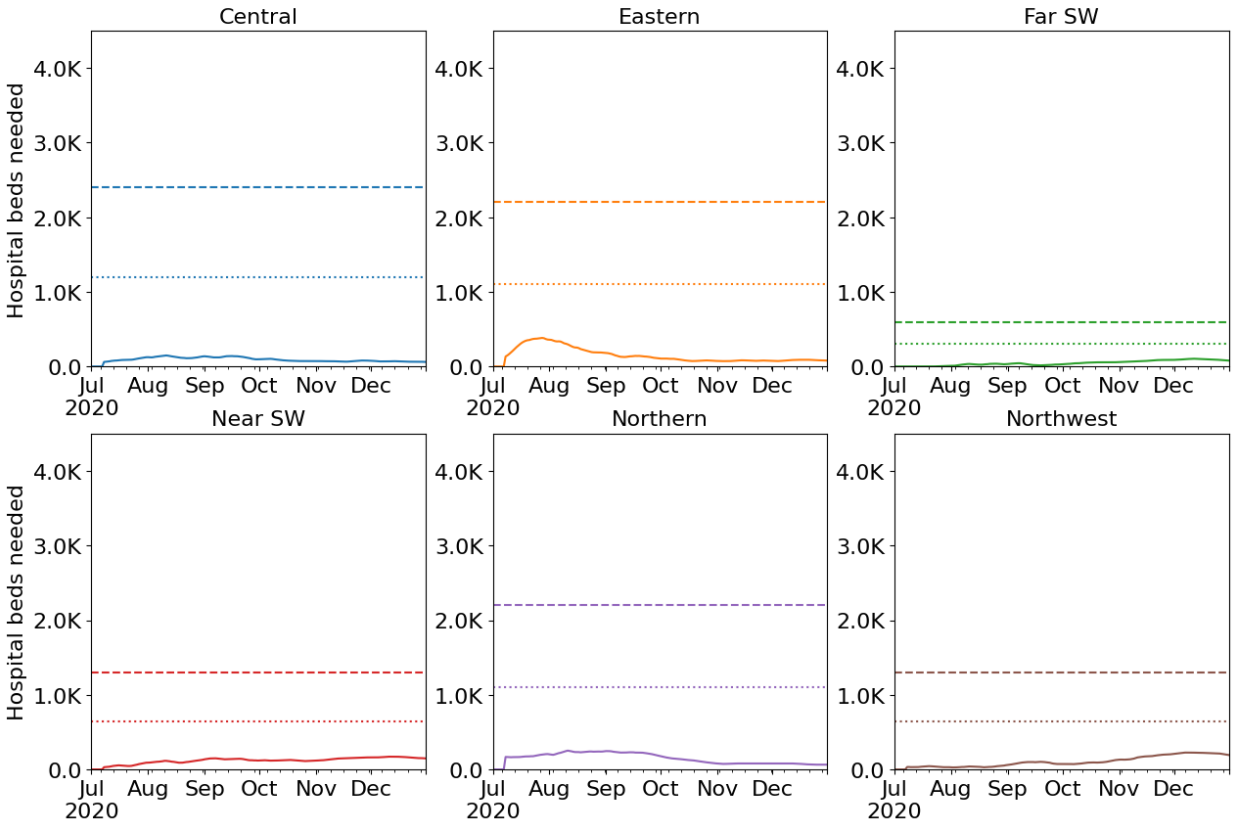
- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario



Hospital Demand and Bed Capacity by Region

Capacities by Region – Adaptive-High

COVID-19 capacity ranges from 80% (dots) to 120% (dash) of total beds



Week Ending	Adaptive	Adaptive-High
10/11/20	6,369	6,369
10/18/20	7,014	7,017
10/25/20	7,319	7,369
11/1/20	7,567	8,899
11/8/20	8,024	11,577
11/15/20	8,323	13,613
11/22/20	8,394	15,105
11/29/20	8,161	15,905
12/06/20	7,770	16,003
12/13/20	7,285	15,558
12/20/20	6,728	14,662
12/27/20	6,077	13,577

Based on Adaptive-High scenario: no regions forecast to exceed capacity

* Assumes average length of stay of 8 days

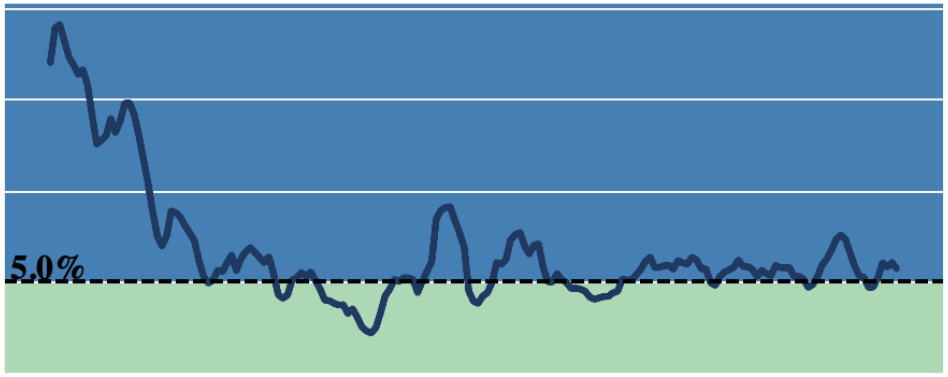
Health Care System Challenges

Health care worker capacity limited by high infection rate

HC WORKERS

What percent of cases are among healthcare workers?
High Threshold = 5%

5.7%



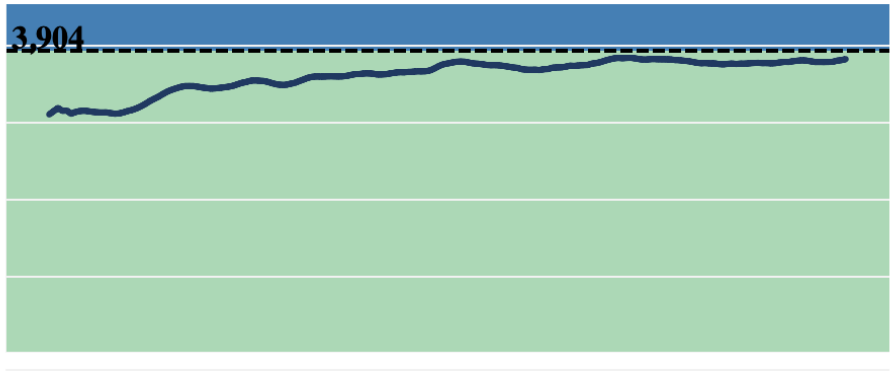
The percent of cases among HCWs has been increasing for **3 days**. This does not exceed the threshold of 7 days, so the percent of cases among HCWs is considered to be **fluctuating**.

Increased bed use during the fall and winter

HOSPITAL BEDS

What percent of hospital beds are currently occupied?
High Threshold = 90%

87.5%



The percent of occupied beds has been increasing for **27 days**. This exceeds the threshold of 14 days, so the percent of occupied beds is considered to be **increasing**.

From VDH Pandemic Metrics dashboard: https://www.vdh.virginia.gov/coronavirus/key-measures/pandemic-metrics/region-metrics/

Key Takeaways

Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

- **Shifting back towards growth, several districts surging with highest yet levels of case rates.**
- VA weekly incidence (12/100K) is up but still below the climbing national average (19.6/100K).
- Projections are mixed, many districts continue to decline, but most are flat or growing.
- Recent updates:
  - Improved smoothing of Adaptive Fitting projections to minimize artifacts.
  - Planning Scenarios moved up to Oct 21st to respond to resurgence in VA and across nation.
- The situation is changing rapidly. Models will be updated regularly.

References

Venkatramanan, S., et al. "Optimizing spatial allocation of seasonal influenza vaccine under temporal constraints." *PLoS computational biology* 15.9 (2019): e1007111.

Arindam Fadikar, Dave Higdon, Jiangzhuo Chen, Bryan Lewis, Srinivasan Venkatramanan, and Madhav Marathe. Calibrating a stochastic, agent-based model using quantile-based emulation. SIAM/ASA Journal on Uncertainty Quantification, 6(4):1685–1706, 2018.

Adiga, Aniruddha, Srinivasan Venkatramanan, Akhil Peddireddy, et al. "Evaluating the impact of international airline suspensions on COVID-19 direct importation risk." *medRxiv* (2020)

NSSAC. PatchSim: Code for simulating the metapopulation SEIR model. https://github.com/NSSAC/PatchSim (Accessed on 04/10/2020).

Virginia Department of Health. COVID-19 in Virginia. http://www.vdh.virginia.gov/coronavirus/ (Accessed on 04/10/2020)

Biocomplexity Institute. COVID-19 Surveillance Dashboard. https://nssac.bii.virginia.edu/covid-19/dashboard/

Google. COVID-19 community mobility reports. https://www.google.com/covid19/mobility/

Biocomplexity page for data and other resources related to COVID-19: https://covid19.biocomplexity.virginia.edu/

Questions?

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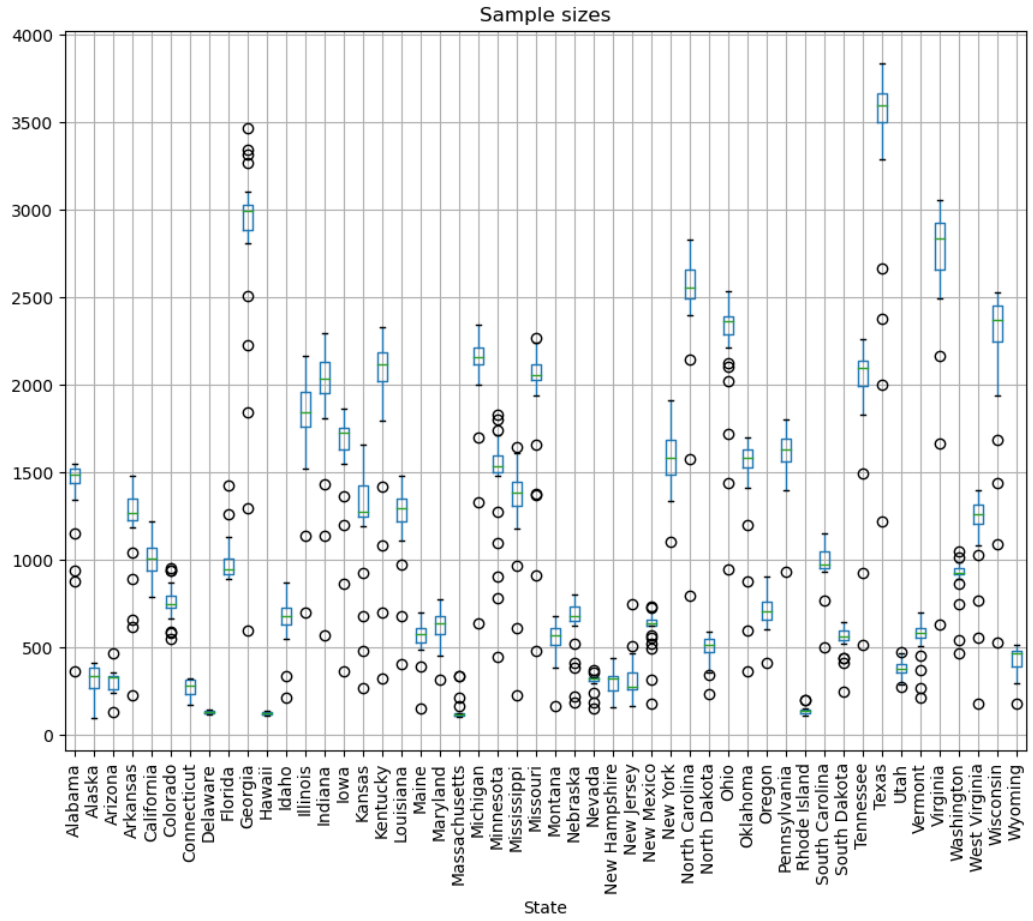
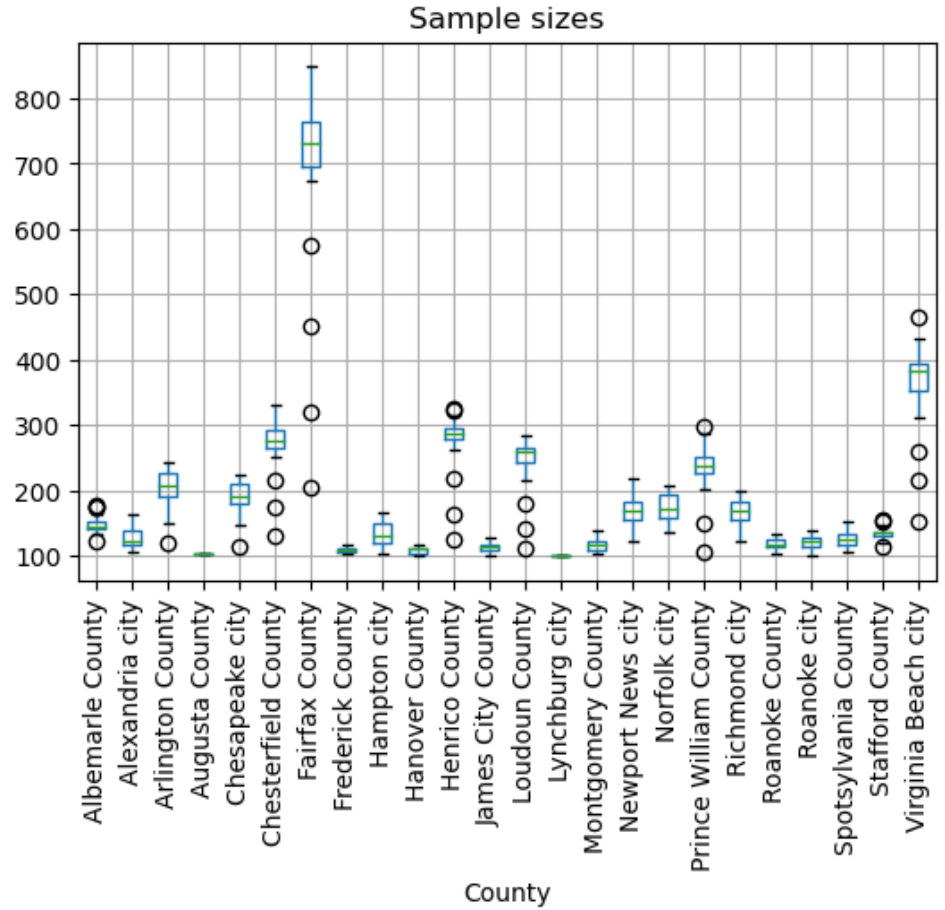
Supplemental Slides

Mask usage sample sizes





Test positivity across VA counties

- CMS weekly summary (used for guiding nursing homes testing protocol)
- Data: COVID-19 Electronic Lab Reporting (CELR); HHS Unified Testing Dataset;
- County level testing counts and test positivity rates for RT-PCR tests.
  - Green: Test positivity <5.0% or with <20 tests in past 14 days
  - Yellow: Test positivity 5.0%-10.0% or with <500 tests and <2000 tests/100k and >10% positivity over 14 days
  - Red: >10.0% and not meeting the criteria for "Green" or "Yellow"

https://data.cms.gov/stories/s/q5r5-gjyu

County	Sep-16	Sep-23	Sep-30	Oct-07
Amherst County	Yellow	Yellow	Yellow	Red
Bedford County	Yellow	Yellow	Yellow	Red
Campbell County	Yellow	Yellow	Yellow	Red
Charlotte County	Yellow	Green	Red	Red
Dinwiddie County	Yellow	Yellow	Yellow	Red
Franklin County	Yellow	Red	Red	Red
Greensville County	Red	Yellow	Red	Red
Manassas City	Yellow	Red	Yellow	Red
Martinsville City	Yellow	Yellow	Yellow	Red
Mathews County	Yellow	Yellow	Red	Red
Pittsylvania County	Red	Red	Red	Red
Prince George County	Yellow	Red	Red	Red
Rockingham County	Red	Red	Red	Red
Southampton County	Red	Red	Red	Red
Suffolk City	Red	Yellow	Yellow	Red
Surry County	Red	Red	Red	Red
Washington County	Red	Yellow	Red	Red
Wise County	Yellow	Yellow	Yellow	Red

Red on Oct-07

County	Sep-16	Sep-23	Sep-30	Oct-07
Augusta County	Red	Red	Yellow	Green
Bland County	Red	Yellow	Green	Green
Bristol City	Red	Yellow	Yellow	Yellow
Caroline County	Red	Yellow	Yellow	Yellow
Danville City	Red	Yellow	Yellow	Yellow
Fairfax County	Red	Yellow	Yellow	Yellow
Franklin City	Red	Red	Yellow	Yellow
Grayson County	Red	Red	Red	Yellow
Greensville County	Red	Yellow	Red	Red
Hanover County	Red	Yellow	Yellow	Yellow
Harrisonburg City	Red	Red	Red	Yellow
Henry County	Red	Red	Red	Yellow
Isle of Wight County	Red	Yellow	Yellow	Yellow
King and Queen County	Red	Yellow	Yellow	Green
Lancaster County	Red	Red	Yellow	Yellow
Loudoun County	Red	Yellow	Yellow	Yellow
Montgomery County	Red	Red	Yellow	Yellow
Northumberland County	Red	Red	Yellow	Yellow
Nottoway County	Red	Yellow	Yellow	Yellow
Pittsylvania County	Red	Red	Red	Red
Portsmouth City	Red	Red	Yellow	Yellow
Prince William County	Red	Yellow	Yellow	Yellow
Pulaski County	Red	Red	Yellow	Green
Radford City	Red	Yellow	Green	Green
Roanoke City	Red	Yellow	Yellow	Yellow
Roanoke County	Red	Red	Yellow	Yellow
Rockingham County	Red	Red	Red	Red
Salem City	Red	Red	Yellow	Yellow
Smyth County	Red	Yellow	Yellow	Yellow
Southampton County	Red	Red	Red	Red
Staunton City	Red	Yellow	Green	Green
Suffolk City	Red	Yellow	Yellow	Red
Surry County	Red	Red	Red	Red
Sussex County	Red	Red	Red	Yellow
Washington County	Red	Yellow	Red	Red

Red on Sep-16

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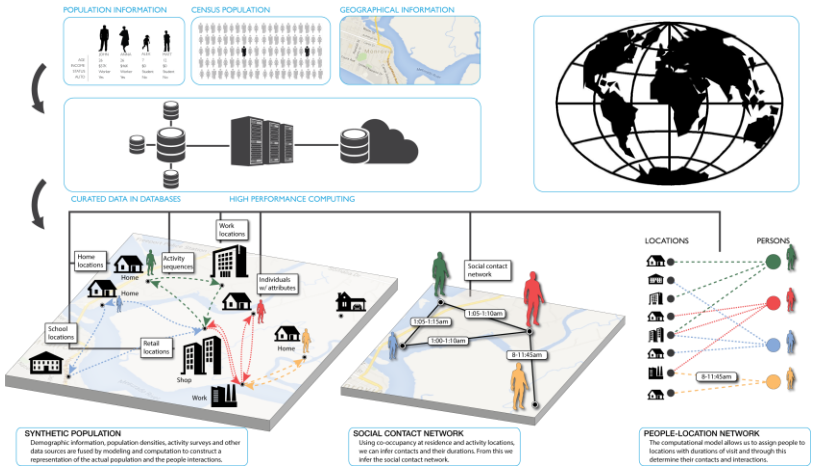
Agent-based Model (ABM)

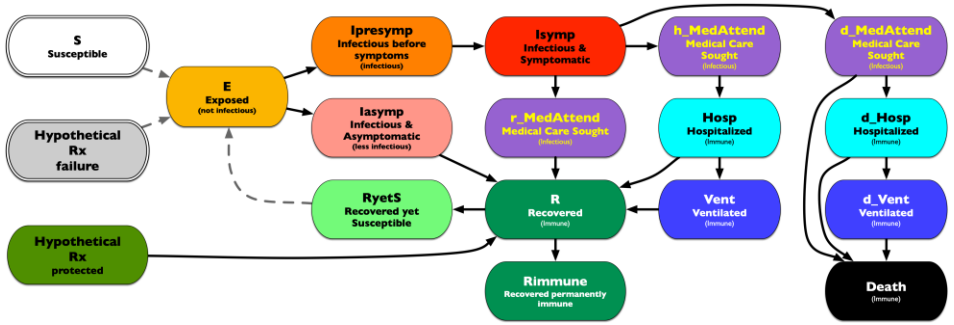
EpiHiper: Distributed network-based stochastic disease transmission simulations

- Assess the impact on transmission under different conditions
- Assess the impacts of contact tracing



Synthetic Population

- Census derived age and household structure
- Time-Use survey driven activities at appropriate locations



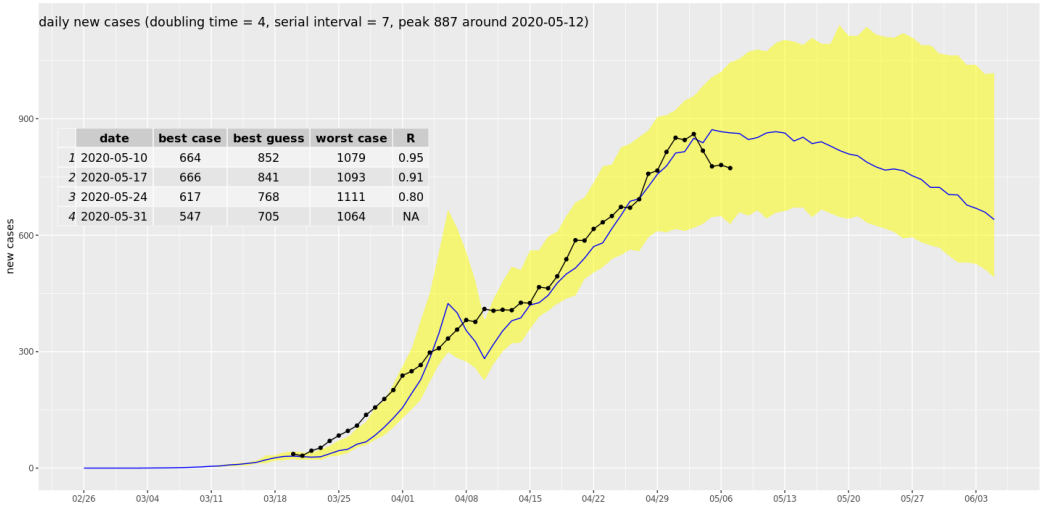
Detailed Disease Course of COVID-19

- Literature based probabilities of outcomes with appropriate delays
- Varying levels of infectiousness
- Hypothetical treatments for future developments

ABM Social Distancing Rebound Study Design

Study of ”Stay Home” policy adherence

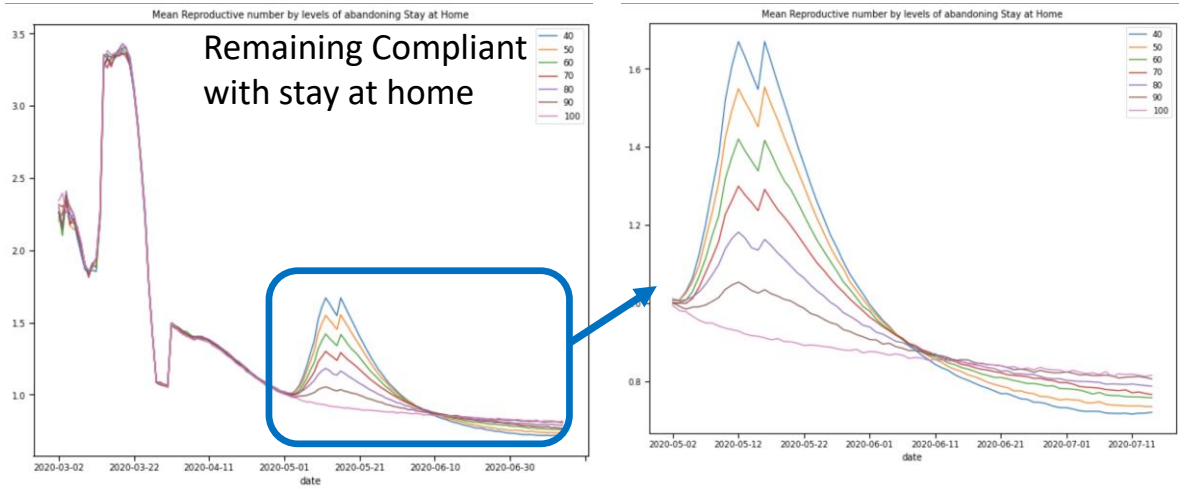
- Calibration to current state in epidemic
- Implement “release” of different proportions of people from ”staying at home”



	date	best case	best guess	worst case	R
1	2020-05-10	664	852	1079	0.95
2	2020-05-17	666	841	1093	0.91
3	2020-05-24	617	768	1111	0.80
4	2020-05-31	547	705	1064	NA

Calibration to Current State

- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim

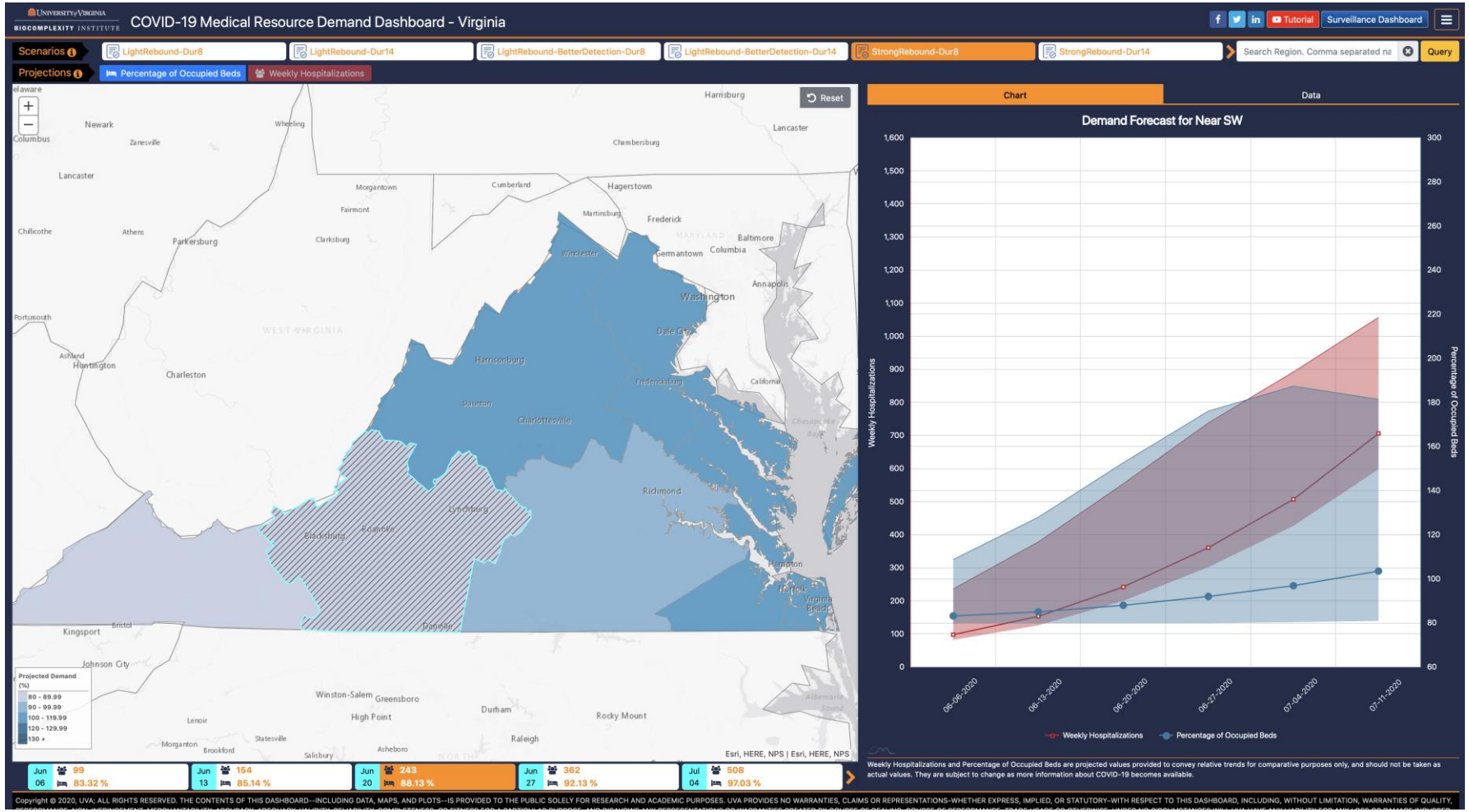


Impacts on Reproductive number with release

- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a 1/6th return to pre-pandemic levels

Medical Resource Demand Dashboard

https://nssac.bii.virginia.edu/covid-19/vmrddash/



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